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LEVEL II

FLAME TUBE AND BALLISTIC EVALUATION OF EXPLOSAFE ALUMINUM FOIL FOR AIRCRAFT FUEL TANK EXPLOSION PROTECTION

Fire Protection Branch
Fuels and Lubrication Division

April 1980

TECHNICAL REPORT AFWAL-TR-80-2031

Final Report for Period August 1977 to March 1979

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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This technical report has been reviewed and is approved for publication.

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This report presents the combustion and gunfire testing conducted by the AFWAL/PO and the AVRADCOM/Applied Technology Laboratory in support of a joint USAF/Army and Canadian Government project to evaluate an advanced metal foil explosion suppressor called Explosafe for potential use in protecting aircraft fuel tanks. This material is manufactured by Vulcan Industrial Packaging Limited, (VIPL), Explosafe Division, and is processed by slitting, expanding and stacking aluminum foil into batts. The density is varied either by changing the foil thickness at a constant expansion width or by changing the expansion width at a

constant foil thickness. The scope of this in-house program was to determine: (1) the material's ability to suppress combustion overpressures through small scale laboratory testing and through full scale ballistic testing, (2) to establish an optimum material density versus performance and (3) to compare the results to the reticulated polyurethane foam.

no./cu ft

The AFWAL/PO conducted the laboratory tests in a flame tube over several densities of 3 foil thicknesses and the Army conducted the ballistic tests in a heavy structual fuel tank over 3 densities of 3 foil thicknesses. Results of these tests indicated that a 2.0 mil foil around the 2.0 ~~#/ft³~~ region was an optimum foil thickness and weight density to be used in the remaining tests of the joint program. The lab tests showed that the performance of the 2.17#/ft³ 2.0 mil foil was slightly worse than the performance of the blue coarse polyurethane foam and the ballistic tests indicated that these two materials were comparable in performance. The ballistic tests also showed that the damage inflicted to the 2.0 mil foil was comparable to the foam. Both test series showed that the 3.0 mil foil has the best combustion suppression but the density is much higher than the foam and the 2.0 foil. The 1.5 mil foil has a density closer to polyurethane foams but performance is much worse at this low weight.

These tests are part of the total evaluation process to qualify candidate explosion suppressor materials for aircraft use. The currently used polyurethane foams are evaluated under Mil-B-83054 (Reference 1). Since Explosafe is made from aluminum foil many of the tests under Mil-B-83054 are not applicable but this joint program has developed sufficient information that can be used to develop a military specification for candidate materials made of metal. The Explosafe material is not necessarily intended to completely replace the polyurethane foams but rather to be used in specific applications where it is advantageous. Explosafe has a potentially longer service life and can be used in higher temperature environmental applications. The material has been installed successfully in external drop tanks, bladder cells and integral fuel tanks of various internal complexities. However, installation in fuel tanks with small access ports may be a problem and removal of the material for fuel tank inspections would require extreme care by maintenance personnel since it can be easily damaged if handled improperly. The development of installation criteria is being addressed directly by VIPL as part of this overall joint program.

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FOREWORD

This report describes two in-house efforts conducted by personnel of the Fire Protection Branch (POSH), Fuels and Lubrication Division (POS), Aero-Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under Project 3048, "Fuels, Lubrication, and Fire Protection," Task 304807, "Aerospace Vehicle Fire Protection," Work Units 30480773 and 30480787, "Aircraft Fire Protection," and by personnel of the Safety and Survivability Technical Area, Applied Technology Laboratory, U.S. Army Research and Technology Laboratory (SAVDL-ATL-ASV), Fort Eustis, Virginia, under the U.S. Army 6.2 program, Exploratory Development, Military Application Projects 1L162209AH76, Safety and Survivability, AMCMS Code 612209.H76 0512, Line Item 23A, House Task 74-14.

These in-house efforts are in support of a joint USAF/U.S. Army and Canadian Government program to evaluate and optimize the metal foil explosion suppressor, Explosafe, for potential use in protection of aircraft fuel tanks. This joint program was initiated in April 1976 and a formal contract was started in June 1977.

The AFWAL/PO work reported herein was performed during the period August 1977 to October 1978, under the direction of the author, Mr. T. A. Hogan, project engineer. The U.S. Army work reported herein was performed during the period of August 1977 to March 1979 under the direction of the author, Mr. C. Pedriani, project engineer. The authors wish to thank Mr. T. Allen of the AFWAL/POSH, Mr. T. O. Reed of the ASD/ENFEF, Mr. E. Pard, Mr. C. Harrison and Mr. R. Bott of the DAVDL-ATL and Mr. A. Szego, Mr. R. Appleyard, and Mr. K. Premji of Vulcan Industrial Packaging Limited, Explosafe Division for their assistance in support of the tests. The author submitted the report in February 1980.

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SECTION I

INTRODUCTION

1. OBJECTIVES

This program was conducted in support of a joint USAF/Army and Canadian Government program directed at evaluating, optimizing and generating a product specification for a metal matrix material called Explosafe for aircraft fuel tank explosion protection. Under this joint program the material was subjected to a number of tests and studies. The manufacturer of the material, Vulcan Industrial Packaging Limited (VIPL), has conducted environmental exposure tests, slosh and vibration tests, installation criteria and packing density studies, and fluid displacement and retention studies. The USAF and Army conducted tests to evaluate the material's ability to suppress the combustion overpressure associated with the ignition of flammable fuel vapor and air mixtures within a fuel tank. This report contains the test data generated by the Aero-Propulsion Laboratory (AFWAL/PO) and the U.S. Army on this material.

a. AFWAL/PO Flame Tube Testing

The objective of performing the flame tube tests was to establish the material's ability to suppress combustion overpressures and to compare these results to polyurethane foams. Also, this testing was to establish an optimum material thickness and density based on its suppression performance and other properties in order to use a standard material for the remaining tests of the joint program.

b. U.S. Army Ballistic Testing

The objective of performing the ballistic testing was to derive an empirical evaluation of the ability of Explosafe to reduce fuel tank ullage combustion overpressures resulting from Armor-Piercing Incendiary (API) and High Energy Incendiary-Threat (HEI-T) impacts. One of the key factors in determining the suitability of Explosafe for use in combat aircraft is its ability to preclude fuel tank damage as a consequence of API or HEI-T ullage impact. Although laboratory tests can provide a preliminary indication of the performance of a candidate fuel tank filler, full-scale ballistic tests provide the confidence necessary to proceed through engineering development phases and fleet application with minimum risk. Similar tests were conducted with 15 pores per inch blue reticulated hybrid polyester urethane foam (Reference 1) for comparison purposes.

2. BACKGROUND

The Air Force and the Army are constantly looking for improved methods to protect aircraft from combat damage and the fuel system is one of the largest vulnerable areas of an aircraft because of the risk of fire and explosion from hostile ignition sources. The space in a fuel tank above the liquid fuel level is called the ullage and contains fuel vapors and air. The ignition of a flammable mixture of fuel vapor and air in the unprotected ullage can result in structural damage to the aircraft from the combustion overpressure. The degree of damage is directly related to the threat and fuel conditions (References 2 through 7).

During operations in Southeast Asia (SEA) in the late 1960's the Air Force began installing reticulated (open cell) polyester urethane foam in the fuel tanks of most combat aircraft to reduce the effects of incendiary projectile hits (References 2 through 8). The foam and other baffle materials protect the fuel tank by reducing: (a) the combustion overpressure in the ullage, (b) the blast and fragment damage to the fuel tank and (c) the fuel sloshing during flight. The use of the polyurethane foams has been one of several methods successful in protecting the fuel tank but there are several penalties which include the weight, fuel displacement and retention, and short service life due to foam degradation by high humidity and high temperature. The weight of the foam imposes a severe penalty on large aircraft and lesser penalty on fighter type aircraft.

The reticulated foams in addition to other materials can be put into two classifications with respect to their combustion overpressure and fire suppression characteristics. Based on the installation criteria the fine pore (small hole) foam is identified as a flame arrestor and the coarse pore (large hole) foam is a combustion overpressure suppressor. Both types of foam will suppress a combustion overpressure but the fine pore foam in the proper configuration will arrest the flame and the coarse pore foam (and Explosafe) will let the flame pass through (References 9 through 12). If a fire continues in the fuel tanks due to an air source such as projectile holes, then the polyurethane foams can also continue to burn, but so would the fuel. Consequently, in a closed environment combustibility of the foam material is not a major concern.

The Air Force is currently using two types of reticulated foam in aircraft fuel tanks: (a) polyester polyurethane and (b) hybrid polyether polyurethane. The performance to suppress combustion overpressures is comparable for the two types of foam. The polyester foam was the first and currently the most widely used. Experience in SEA has shown that in the severe environments of high temperatures and high humidity the service life varied from two to five years but in less severe environments this foam will last much longer (Reference 13). As the foam degrades and breaks down it contaminates the fuel systems and can clog fuel filters. The hybrid polyether foam was developed to provide better hydrolytic stability and it exhibits a service life much greater than the polyester foams (References 14 through 19). The hybrid polyether foam is used experimentally in several aircraft and is being reviewed by ASD/ENFEF. It is being considered for a few types of new aircraft and for replacement in aircraft now using the polyester foam.

In 1976 a joint USAF/U.S. Army and Canadian Government program was initiated to evaluate Explosafe, a metal explosion suppressor, for potential use in aircraft fuel tanks. Preliminary lab tests on the Explosafe

3.0 mil material showed that the flame passed completely through the material but its ability to limit combustion overpressure was similar to the coarse pore foams. Results of this testing are contained in Appendix B, Table B-2. Since the material was made of aluminum foil its temperature capacity and anticipated service life were greater than any of the foams. The aircraft fuel system penalties associated with Explosafe were similar to the foam. Some factors associated with the installation of Explosafe could limit its application, but the material has been installed successfully in external drop tanks, bladder cells and integral fuel tanks as part of the overall joint program. Other testing done by VIPL consisted of establishing the effects of the material in fuel systems. These results will be contained in a final report to be published at the conclusion of the joint program.

SECTION II

AFWAL/PO FLAME TUBE EVALUATION

1. PROGRAM APPROACH

The physical properties of the Explosafe material, which are described in Appendix A, were analyzed for their possible effects on combustion overpressure suppression. Consequently, plans for two series of tests were outlined. The first series was to study the orientation effects and the other was to study the density and surface area effects. The test parameters in each series included two initial pressures of 14.7 and 17.7 psia and void configurations at intervals of 10% up to 40% by volume that could be used in comparison with other explosion suppression materials.

2. TEST EQUIPMENT - AFWAL/PO FLAME TUBE SET-UP

A full description of the test chamber, called the flame tube, and of its associated equipment is given in Appendix B. The flame tube, shown in Figure 1, has inside measurements of 12 x 12 x 90 inches and is capable of withstanding combustion overpressures which can be as high as 120 psig with an initial pressure of 3 psig. The test procedures include filling the tank with the proper amount of Explosafe and igniting the 5% by volume propane to air mixture at position A, Figure 1. The resulting combustion overpressures were measured by strain gage pressure transducers at either location E, G or K.

3. SPECIMEN PREPARATION

The foil shipped to the AFWAL/PO was fanfolded into 12 x 12 x 9 inch batts such that each batt was 10% of the total volume of the flame tube and installed as shown in Figure 2. Most of the batts were slightly oversized (i.e., 12.2 x 12 x 9 inches) during production due to the folding method. The batts edges were then cut at the Aero-Propulsion Laboratory

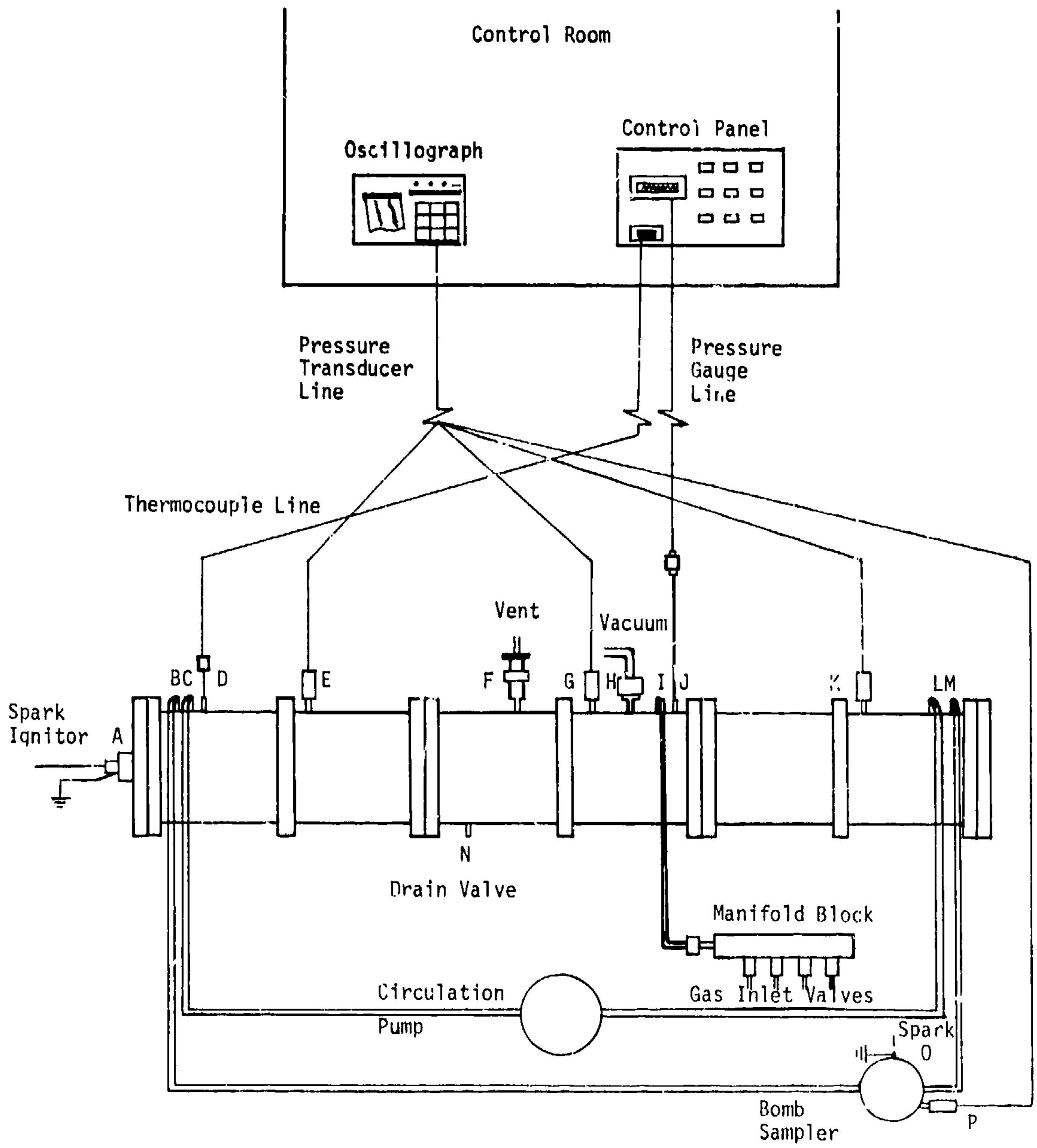


Figure 1. Schematic Diagram of Flame Tube Test Equipment

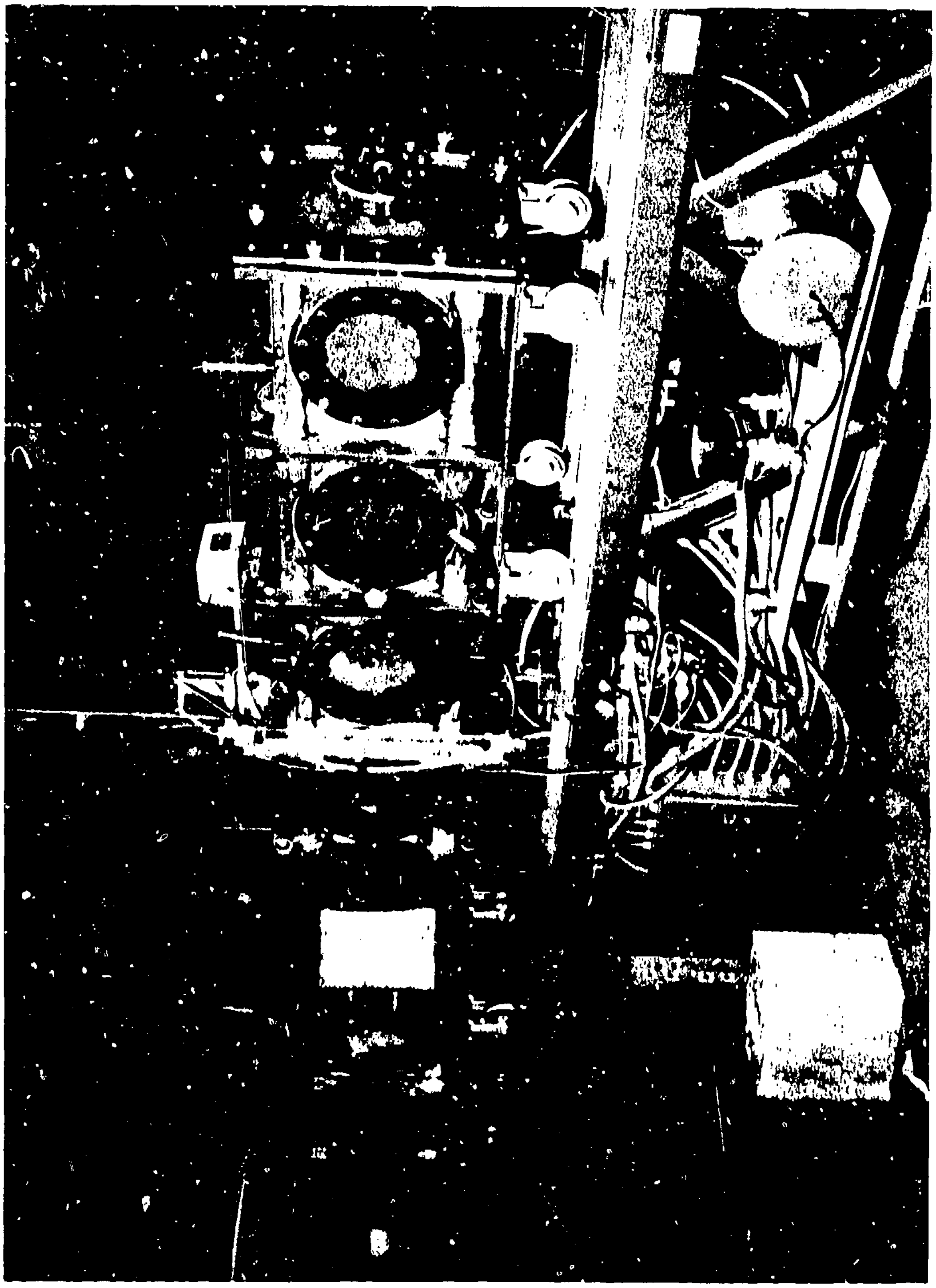


Figure 2. Installation of the Flame Tube

to fit the flame tube but in doing so there were small isolated gaps between the flame tube walls and the batts. This was not considered a serious problem since the combustion flame travels through the material. Also, during shipping several of the batts had settled to approximately 12.2 x 11 x 9 inches in the direction of expansion. These batts included the higher expansions (38 to 44 inches) of the 2.0 and 3.0 mil material and most of the 1.5 mil material. Extreme care was taken to expand these batts to the original dimensions by hand without damaging the shape of the batts. Except for the small voids noted above each batt fit snuggly into the flame tube.

Because of the limited supply of each material thickness most of the batts were reused after each test. After most tests with the combustion void greater than 10% the batts were compressed in two directions (i.e., 12 x 11 x 8) by the pressure wave traveling through the chamber. Although the 9 inch depth of the material usually sprang back once removed from the tank, the other dimension was expanded by hand as noted above. The batts that were damaged most were in the center of the arrestor volume. In the tests with voids of 30% and above these center batts were usually damaged beyond repair and therefore were not used in further testing. The use of repaired batts did not significantly affect the results; the density and surface area of each batt did not change and any growth in void area was less than 1%.

4. TEST RESULTS

a. Baseline Spark Testing

The purpose of the baseline testing was to establish the highest combustion overpressure response to a single spark ignition of a propane/air mixture. This data was generated under previous in-house work and is summarized in Appendix B. Testing was done with two initial pressures, 0 psig and 3 psig and in both cases the peak combustion overpressure occurs at a concentration of 5% by volume. The stoichiometric concentration of propane in air is 4.02% by volume. The testing of Explosafe was therefore done at the 5% by volume concentration.

b. Orientation Effects Study

This study was conducted with the 3.0 mil thick material at a 38 inch expansion, a density of 2.75#/ft^3, a surface area of 130.6 ft^2/ft^3 and initial pressures of 14.7 and 17.7 psia. The three orientations studied are described in Appendix A, Section II. Two sets of data were produced, Set I was completed at the beginning and Set II was completed at the end of the program. Table 1 summarizes the average combustion overpressures of Set II and the test data is in Appendix B, Table B-3. The test results of Set I could not be used in this analysis due to inaccurate packing methods and initial test procedures. After the first set of data was completed the decision was made to continue with the density and surface area testing with the S-33 orientation. This was based on two things: (1) the differences in combustion overpressure between the orientations at the same void levels were small and (2) the S-33 orientation was the easiest to install and handle.

Set II was generated to get a more accurate comparison between the orientations. The results are plotted in Figure 3 and show a small amount of data scatter between orientations for both initial pressures. It is concluded that the orientation of the material is not a significant factor in determining the material's ability to suppress a combustion overpressure.

c. Density and Surface Area Effects Study

This study involved the testing of a range of material thicknesses with several expansion widths. Table 2 shows the average combustion overpressure from the left transducer, P_1, over several parameters. The test data for each material parameter are summarized in Appendix B. The purpose of this testing was to determine an optimum material for weight and combustion response.

The densities used in this program were obtained by changing the foil thicknesses and the expansion widths as noted in Appendix A,

TABLE 1

SUMMARY OF TEST RESULTS OF ORIENTATION STUDY, SET II

Initial Pressure P_I (psia)	Combustion Void V_c (%)	ΔP_1 (psid) Orientation S-32	S-33	S-34
14.7	0	5.6	6.0	5.0
	10	7.6	9.0	9.5
	20	10.0	11.5	9.5
	30	16.8	15.3	14.0
	40	22.4	23.6	21.5
17.7	0	7.5	9.1	8.4
	10	12.0	13.0	11.5
	20	15.5	13.2	17.8
	30	26.5	30.0	22.0
	40		35.5	27.2

NOTE: Material used was 3.0 mil foil at a 38 inch expansion, 2.75 $\#/ft^3$.

TABLE 2

SUMMARY OF TEST RESULTS OF THE DENSITY AND SURFACE AREA STUDY FROM PRESSURE TRANSDUCER P_1

Combustion Void V_c (%)	Expansion (Inches)	ΔP_1 (psid)					
		P_I, Initial Pressure (psia)					
		14.7			17.7		
		Thickness (mil)					
		1.5	2.0	3.0	1.5	2.0	3.0
0	32	6.4	5.0	3.5	12.5	7.5	6.5
	35		8.0			8.2	
	38	8.8		6.0	16.1		9.1
	44			9.4		13.3	11.6
10	32	7.6		5.5	18.5	13.0	8.5
	35		8.0			12.8	
	38	12.5		9.0	21.5		13.0
	44			12.8		19.8	18.2
20	32	20.5		8.8	23.0	20.6	14.5
	35		11.2			19.3	
	38	16.8		11.5	25.0		13.2
	44			13.4		25.3	26.8
30	32	29.0		12.5	37.0	31.0	25.0
	35		25.5			29.3	
	38	24.8		15.3	38.0		30.0
	44			16.6		34.0	33.0
40	32	37.5		26.5	45.0		43.0
	35					37.0	
	38			23.6			35.5
	44			24.0		51.0	41.8

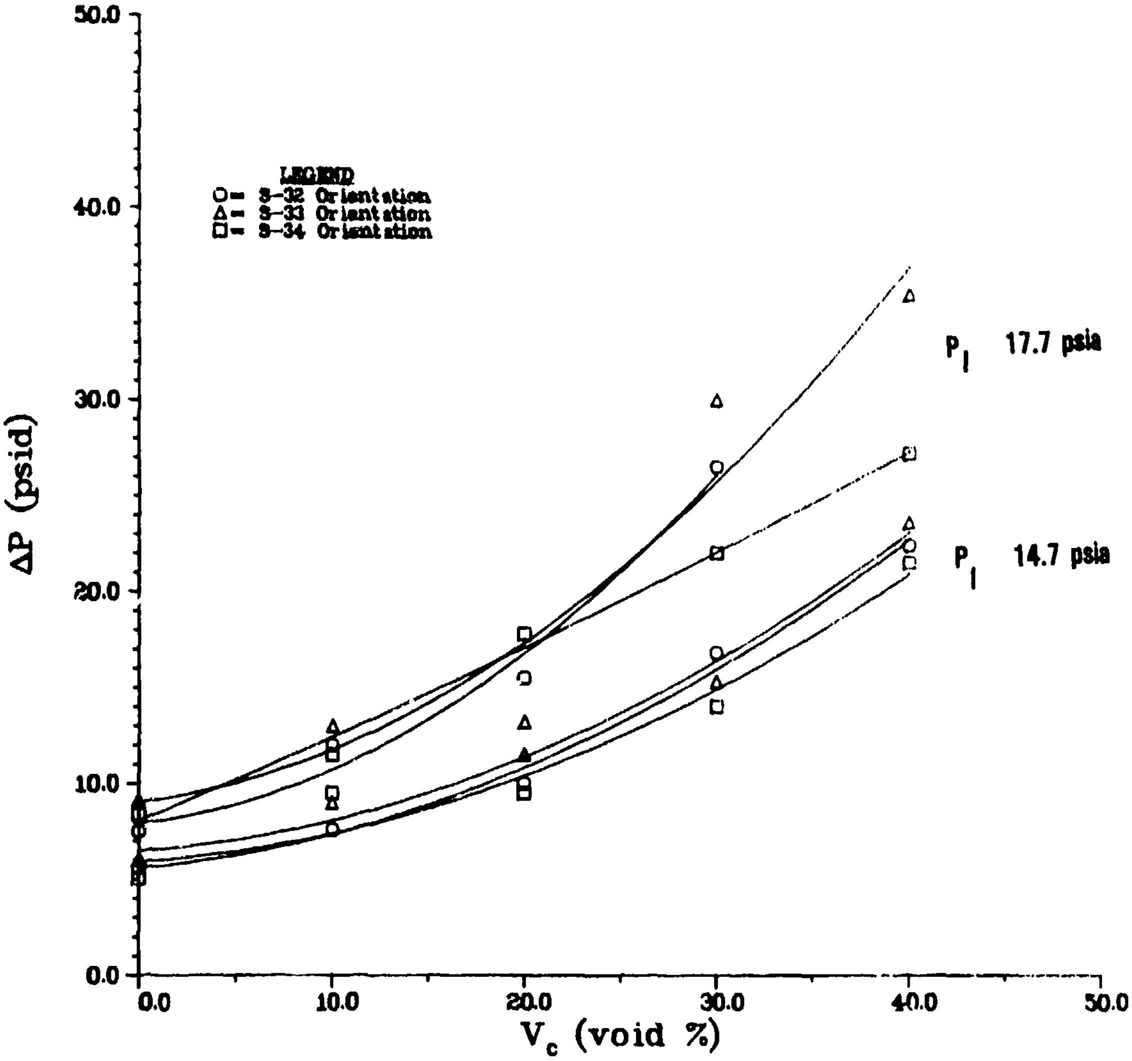


Figure 3. Orientation Study - ΔP Versus V_c - 3.0 mil Foil, 2.75#/ft^3

Section III. The combustion overpressure (ΔP) results of these densities at a P_I = 17.7 psia and V_C = 0% are plotted in Figure 4. As expected the ΔP response increased when the density was decreased as shown in the second order least square fit curve. The ΔP increased from 6.5 psid at 3.54#/ft^3 to 16.1 psid at 1.58#/ft^3.

For each foil thickness the density is proportional to the surface area and inversely proportional to the expansion width. In comparing the results of the foil thicknesses to each other at the P_I = 17.7 psia in Figure 5 the same overall trend of increasing ΔP with decreasing density is observed.

The ΔP response at each foil thickness for the various expansion widths is plotted in Figure 6. For each foil thickness the ΔP rises as the expansion width increases, but this corresponds to the increase in ΔP with decreasing density since the expansion width is inversely proportional to the density at each thickness. For a constant expansion width, i.e., the 32 inch expansion, the ΔP increases with decreasing foil thickness which also corresponds to the increase in ΔP with decreasing density.

Figures 7 and 8 show the same trends as above at the various void levels and initial pressures. Due to a shortage of material the 1.5 and 2.0 mil foils were not fully tested at the 14.7 psia initial pressure. In evaluating the 3.0 mil foil no correlation could be found between the 14.7 and 17.7 psia values. This could be due to the mechanism by which the Explosafe suppresses a combustion reaction which is not completely understood. The testing at 14.7 psia initial pressure shows the same trends but the results are lower than the values at 17.7 psia initial pressure.

Because of the dependence between the density, surface area and expansion width the foil thicknesses must be evaluated separately. Since the density cannot be held constant over a large range, it is very difficult to differentiate between density effects and surface area effects.

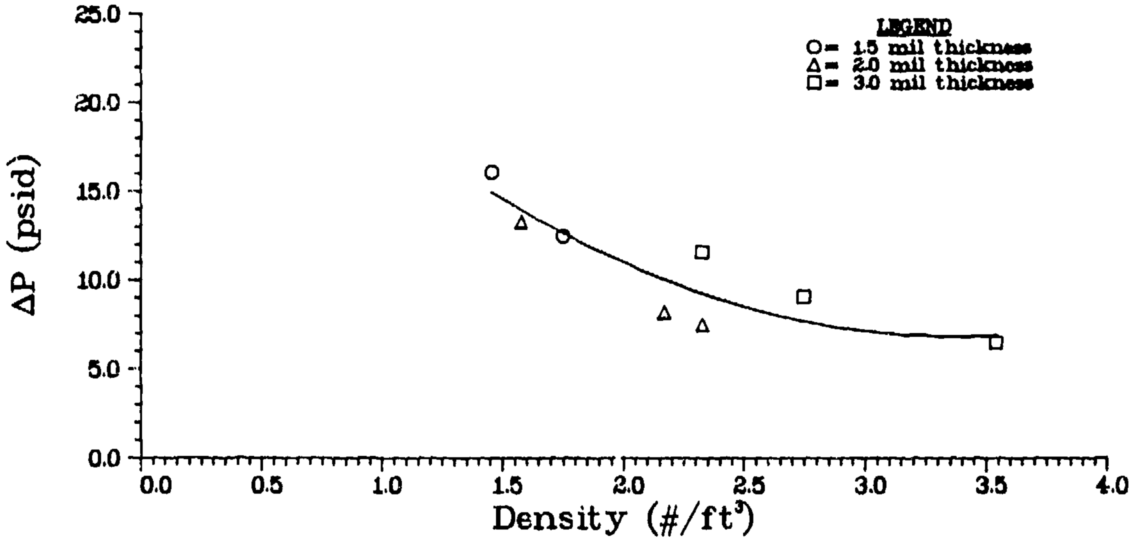


Figure 4. Plot of ΔP Versus Density - P_I = 17.7 psia and V_c = 0%

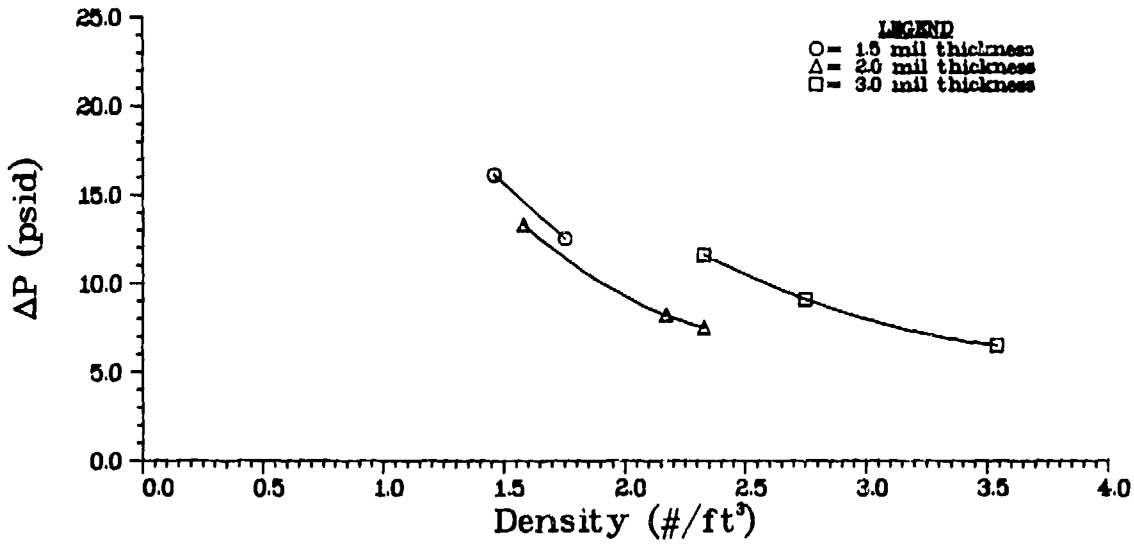


Figure 5. Comparison of Foil Thicknesses - ΔP Versus Density - P_I = 17.7 psia and V_c = 0%

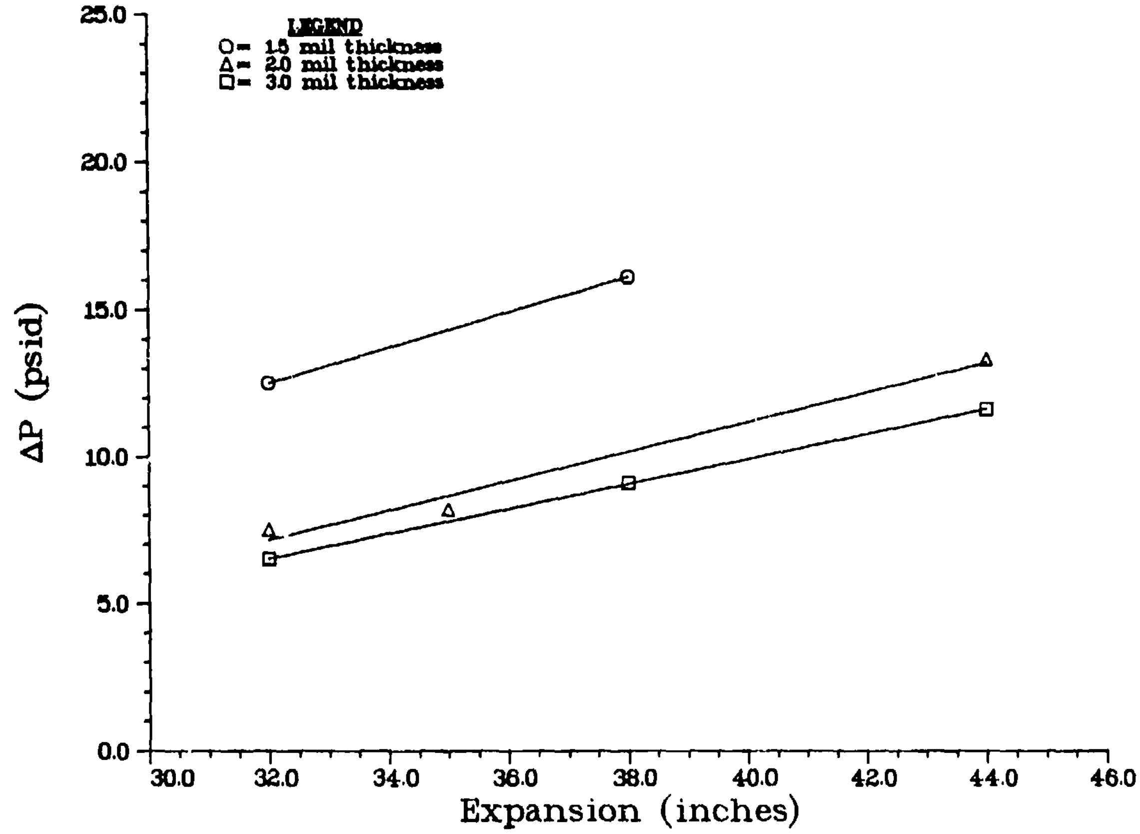


Figure 6. Plot of ΔP Versus Expansion - P_I = 17.7 psia and V_c = 0%

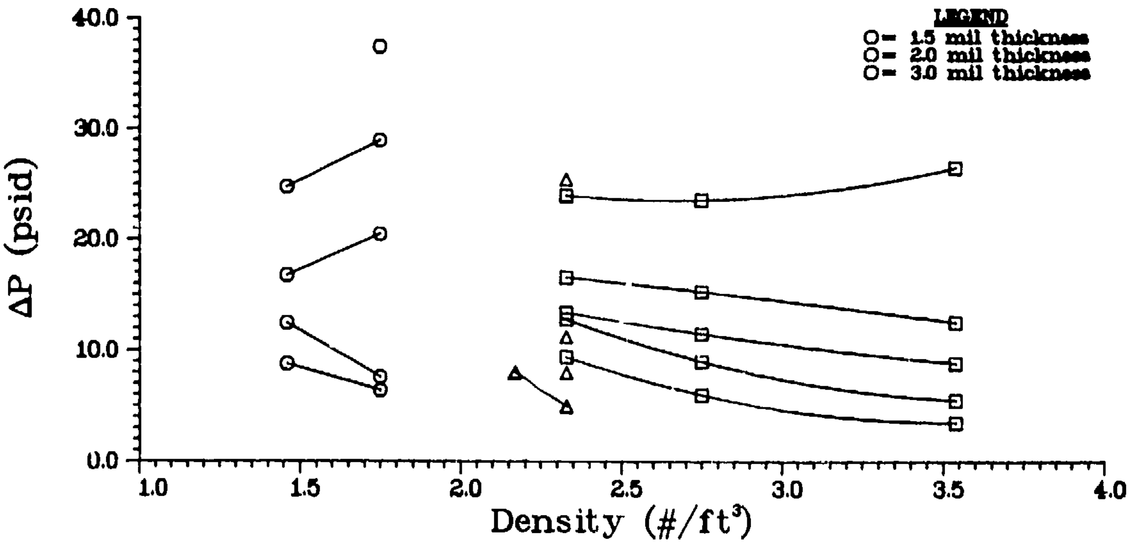


Figure 7a: P_I = 14.7 psia

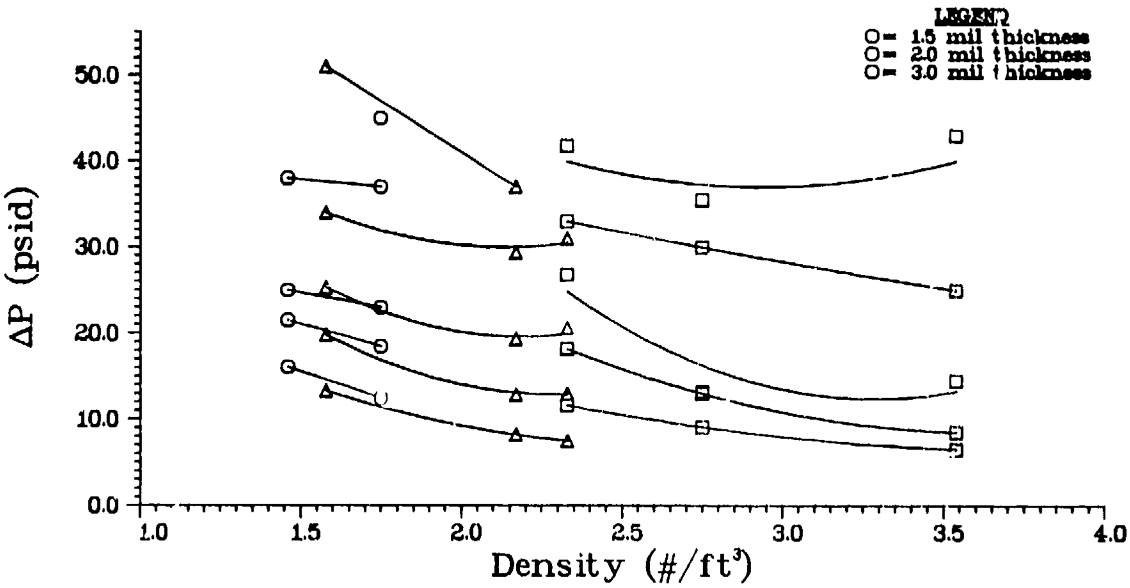


Figure 7b: P_I = 17.7 psia

Figure 7. Summary Plots of ΔP Versus Density

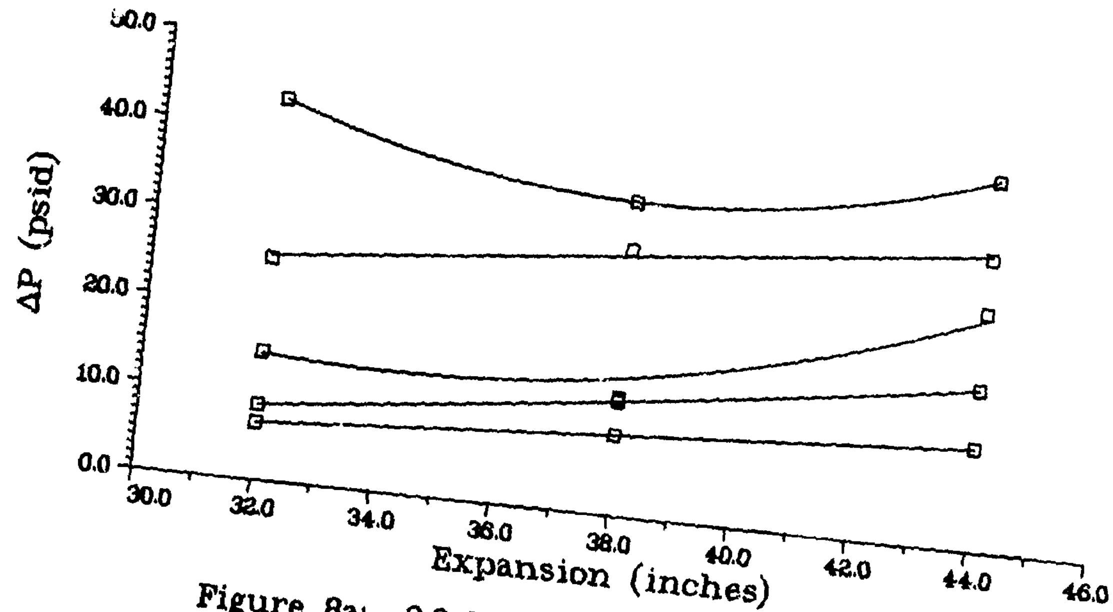


Figure 8a: 3.0 Mil Foil – P_I = 17.7 psia

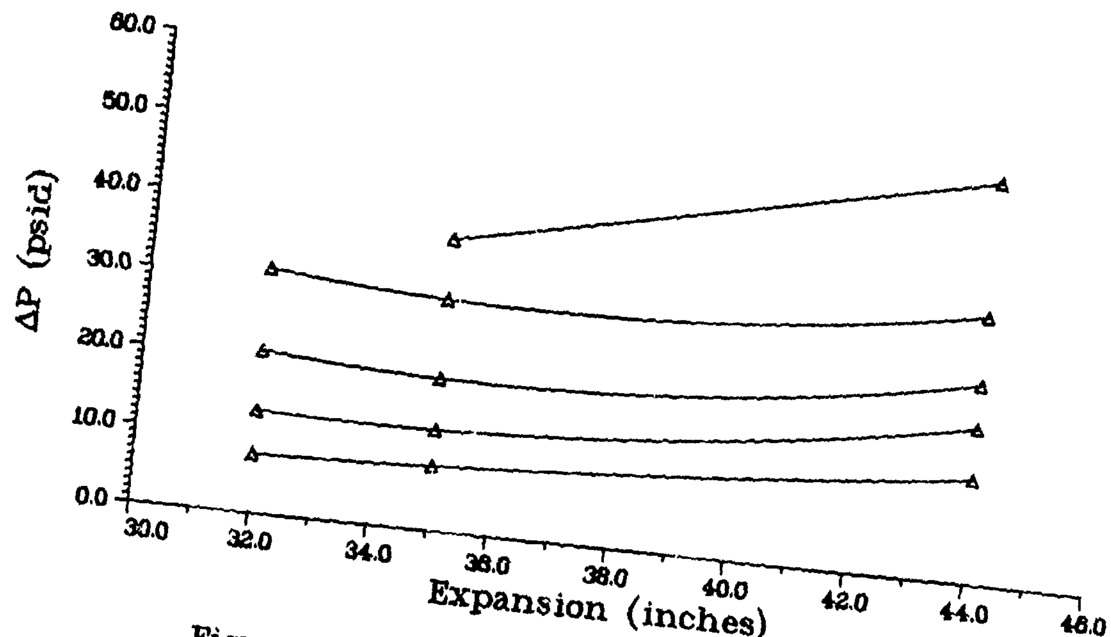


Figure 8b: 2.0 Mil Foil – P_I = 17.7 psia

Figure 8. Summary Plot of ΔP Versus Expansion

The 3.0 mil foil has the best performance at the highest density of 3.54#/ft^3, but, when its density is reduced to 2.33#/ft^3 the ΔP response increased from 6.5 to 11.6 psid. This exceeds the ΔP value of 7.5 psid for the 2.0 mil foil at the same density of 2.33#/ft^3. The lower ΔP response of the 2.0 mil foil at this same density could be due to the higher surface area or the smaller cell size. The cell size may be a dominant parameter with the thicker foils. As shown in Appendix B, the 3.0 mil foil was produced with two strand widths which effects the cell size. The density remains proportional to the surface area through the range of expansion widths. For both configurations the test results show that the smaller cell size configuration (shorter strand width) performs better at the same density and surface area.

The highest combustion overpressures were recorded with the 1.5 mil foil at the 1.58#/ft^3 density. This phenomena was consistent through all the void levels, except at the V_C = 20% and P_I = 17.7 psia where the ΔP of the lowest density 2.0 and 3.0 mil foils slightly exceeded the 1.5 mil foil value. Although the results of the 1.5 mil foil slightly exceed the values of the 2.0 mil foil in the same density range the cell size and surface area are probably not a governing parameter in comparing these two foils. A significant factor could be the rate and amount of heat transfer into the foil.

5. CONCLUSIONS

The purpose of evaluating this foil with a flame tube was to determine the effect of various material parameters on combustion performance and to establish an optimum weight density versus combustion performance that would be comparable to the polyurethane foams. This optimum material was then to be used for the remaining phases of the joint USAF/U.S. Army and Canadian Government program. In establishing this optimum weight several factors were considered: (a) the mil spec for the foams (Reference 1) has a combustion overpressure limit of 15 psid for a V_C = 20% and a P_I = 3 psig, (b) the application of the foil will involve a fully packed configuration with as much as 10% voiding around pumps, fuel lines, etc., and (c) the damage susceptibility due to handling and installation. When evaluating each foil thickness over their densities the 2.0 mil foil around the 2.0#/ft^3 was considered the best possible choice. This value is extrapolated from Figures 4 through 8. At this density and foil thickness the combustion overpressure at a V_C = 10% and at P_I = 3 psig (17.7 psia) is below the 15 psid limit (see Figure 7).

The 3.0 mil material offers the best combustion overpressure suppression performance but the weight is substantially higher than the 2.0 mil foil and the foams. Also as seen in Figures 4 through 8, the 2.0 mil material performs better than the 3.0 mil material at the same density of 2.33#/ft^3. The 2.0 mil material can also be handled as easily as the 3.0 mil material without damaging the batts.

The 1.5 mil material is very light but the density range overlaps the 2.0 mil density range. As seen in Figure 5 and 7 the performance between the 2.0 mil material and the 1.5 mil material in the same density range is negligible. But, extreme care was taken when handling the 1.5 mil material because it was more easily damaged than the 2.0 mil foil.

In the application of this foil a low density configuration, including high void techniques, could be used if the fuel tank is designed to withstand higher pressures. The density could also be reduced if the strand width is reduced. The work by VIPL on the effects of strand width in Appendix B shows that the 3.0 mil material at the 0.040 inch strand width performed better than the 0.055 inch strand width in the same density and surface area ranges (References 20 and 21). This improved performance is attributed to the reduction in cell size. Further evaluation should be done to characterize the 0.040 inch strand width on the 2.0 mil foils.

Since the 2.0 mil foil was chosen to complete the remaining tests of the joint program its performance at P_I = 3 psig is compared to the coarse pore blue foam in Appendix B. The overall suppression performance of the Explosafe is higher than that of the foam. When comparing the materials at a 15 psid combustion overpressure limit the Explosafe stays below this limit at V_c of 10% while the foam stays below this limit at V_c of 20%.

SECTION III

U.S. ARMY BALLISTIC TESTING

1. PROGRAM APPROACH

The level of aircraft fuel tank damage resulting from an ullage explosion is roughly proportional to the pressure generated by the particular reaction. The fuel tank itself can tolerate some internal pressure rise, however, its tolerance is generally much less than the potential pressure rise associated with ullage explosions. Consequently, combat aircraft fuel tanks have been equipped with various tank filler materials which attenuate the combustion pressure. It was decided that the most direct measurement of Explosafe's effectiveness is combustion pressure attenuation.

A rigid steel tank capable of tolerating both HEL blast and fuel/air combustion pressures was used. Baseline tests were conducted with various propane/air mixtures to determine the fuel/air ratio which resulted in the maximum combustion reaction for both API and HEI-T impacts (Appendix C). Each tank filler material was then tested under the worst case conditions at two tank volumes, 15.55 and 40.24 cubic feet, and at full and 40% void installation configurations (see Table 3). The 2.0 mil Explosafe was also tested in a tank volume of 29.93 cubic feet and several void configurations. The combustion pressure was recorded at several locations within the tank and was used as a measure of the filler's effectiveness. The void filler materials tested, blue coarse pore reticulated foam (Reference 1) and three densities of Explosafe were installed in the test tank in both full and 40% gross void configurations. The void was alternately located in the front and the rear of the tank to test projectile detonation both in the void and in the void filler.

The assembled data can be used as preliminary design criteria to make an assessment of these materials for potential use in any specific aircraft application.

TABLE 3

BALLISTIC TEST PARAMETERS

Test Configuration		Material			
Tank		Explosafe			Blue Foam
Vol.	V_c	Thickness (Density)			Density
(ft^3)	(% of Vol.)	1.5 mil (1.85#/ft^3)	2.0 mil (2.06#/ft^3)	3.0 mil (2.72#/ft^3)	1.5#/ft^3
40.24	0	X	X	X	X
	40	X	X	X	X
29.93					
	7.6		X		
	12.0		X		
	15.0		X		
	22.0		X		
	27.0		X		
15.55	0	X	X	X	X
	40	X	X	X	X

2. TEST EQUIPMENT - U.S. ARMY BALLISTIC SET-UP

A photograph of the test site is shown in Figure 9 and the relative locations of key test equipment are shown in Figure 10. Schematics of the three internal tank volume configurations and pressure transducer locations are shown in Figure 11. The test tank components were constructed by Systems Research Laboratory (SRL) in Dayton, Ohio and the exact dimensions of each section are contained in the SRL engineering drawings as follows: the "F" tank and extension assembly reference numbers are 7554-35-3589 through 7554-35-3599 and the "W" tank extension assembly reference numbers are 7507-02-1227 through 7507-02-1230. All the components are interchangeable except between the "F" tank and its extension section. The basic tank wall material was 1-inch-thick stainless steel reinforced with gussets and supported at the corners with 3-by-4 inch posts such that the tank could contain the blast and combustion overpressures from a projectile. These walls were lined with removable 1/4-inch-thick aluminum plates to absorb most of the fragment damage.

A schematic diagram of the equipment used to control tank atmosphere is shown in Figure 12. The output from the piezo resistive transducers was fed into a Sangamo SABRE VI magnetic tape recorder through Vishey amplifiers. The analog data was converted to digital format for processing using the equipment shown in Figure 13. A test to document the frequency response of the data acquisition equipment showed an attenuation of less than 3 decibels at 20 KHz.

A 23mm Mann barrel was used to fire the projectiles. A programmable sequencer was used to control all pretest events and warning signals and to electrically fire the safety breech.

3. TEST PROCEDURE

The gas content of the tank was controlled in the following manner. After the camera window and entrance plates were secured, the tank was

Figure 9. Photograph of Test Site at Ft. Eustis

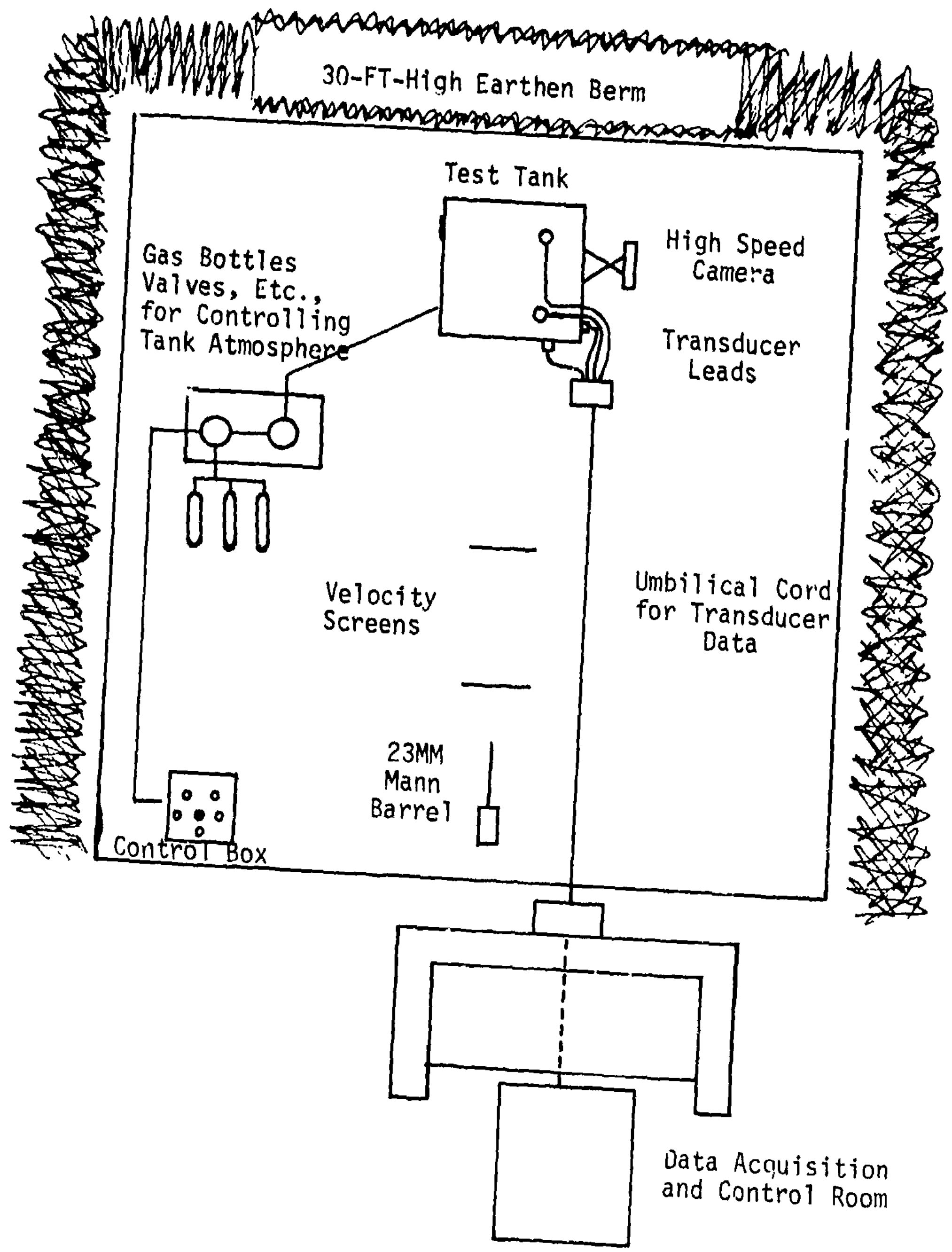
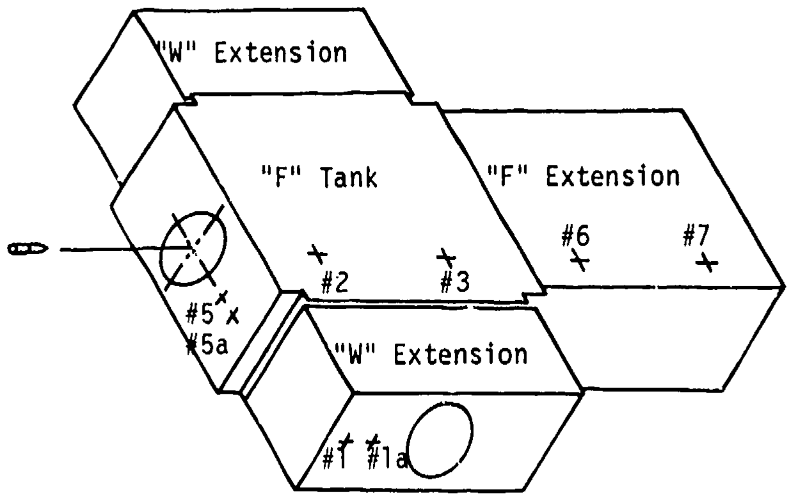


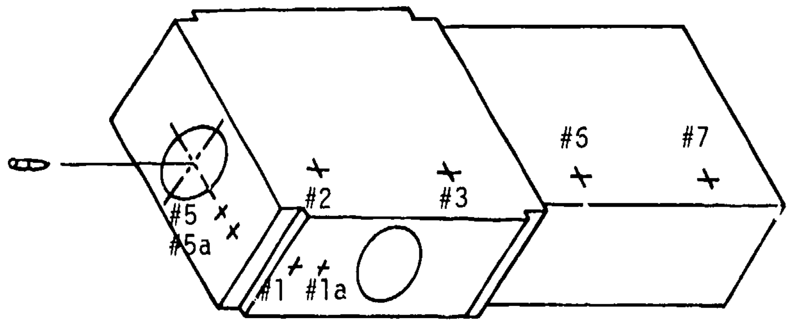
Figure 10. Schematic Diagram of Major Ballistic Test Equipment

+ Indicates Transducer Location



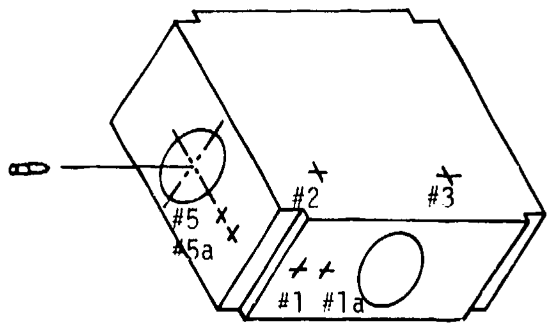
Length = 82.25"
Total Width = 72.25"
Height = 17.25"

Figure 11a: Tank Volume is 40.24 Cubic Feet



Length = 82.25"
Width = 40.25"
Height = 17.25"

Figure 11b: Tank Volume is 29.93 Cubic Feet



Length = 42.25"
Width = 40.25"
Height = 17.25"

Figure 11c: Tank Volume is 15.55 Cubic Feet

Figure 11. Schematic Diagrams of Tank Volumes Showing Inside Configurations

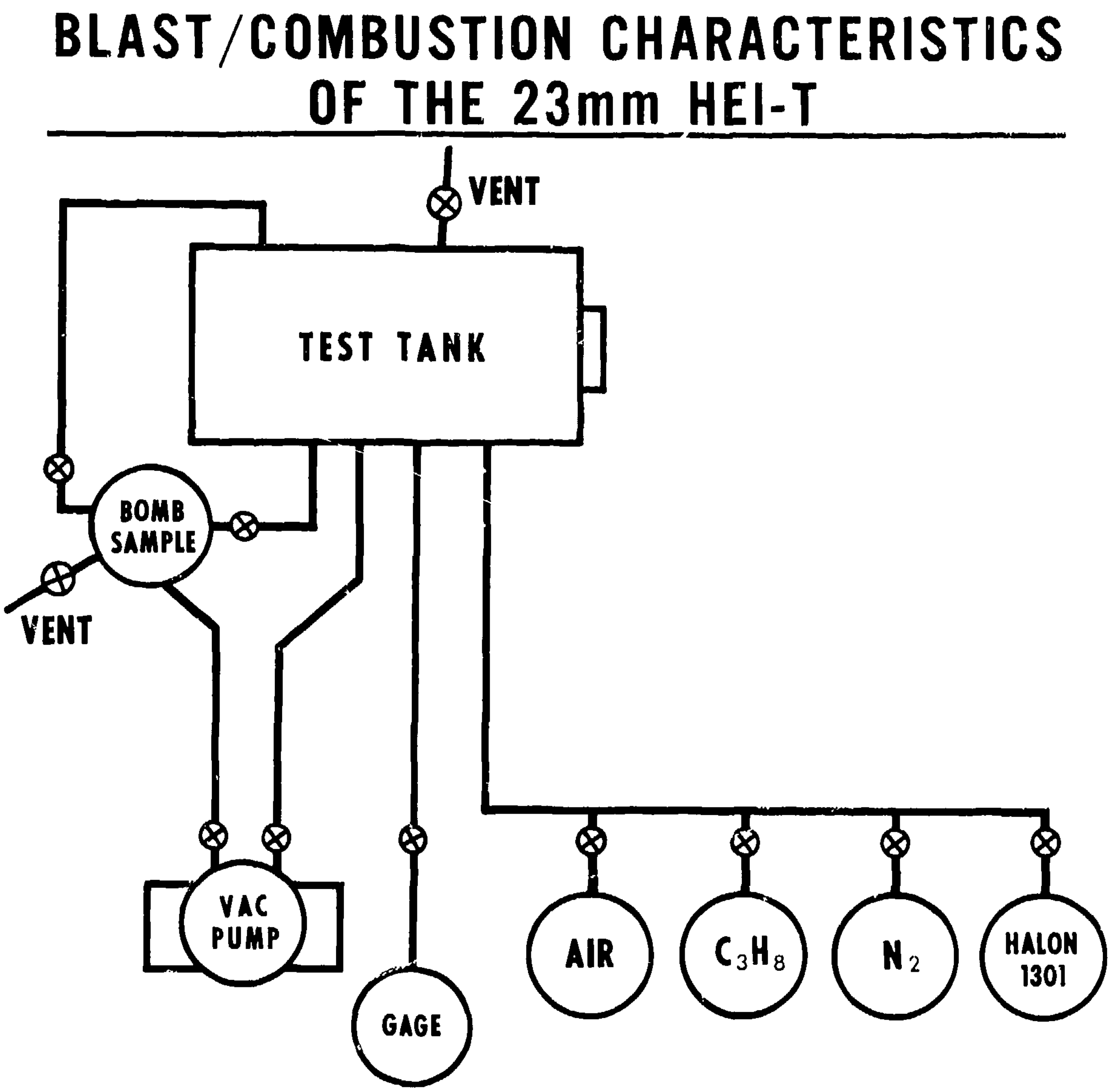


Figure 12. Schematic of Test Equipment to Prepare the Gas Composition of the Test Tank Prior to Ballistic Impact

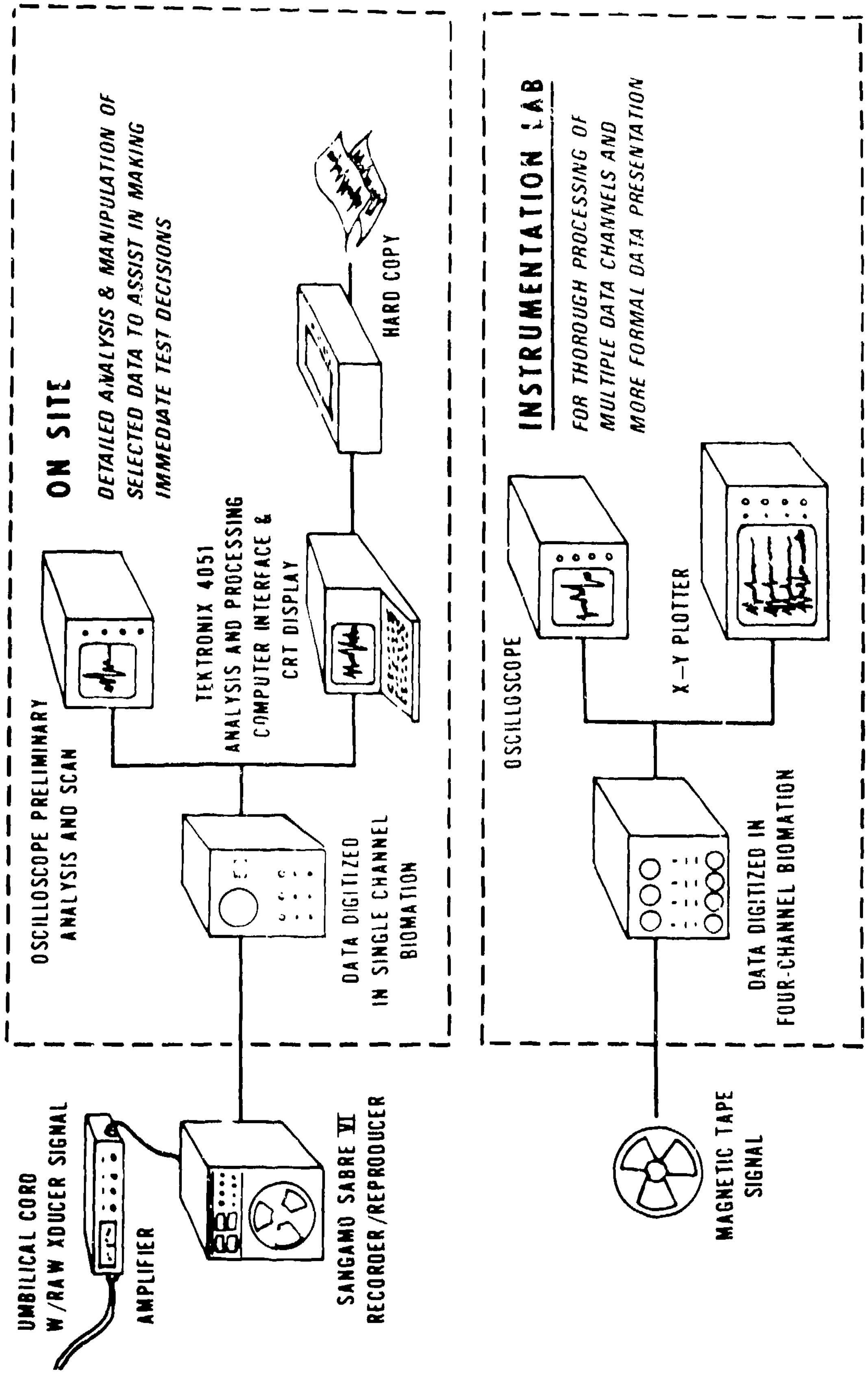


Figure 13. Schematic Diagram of Data Acquisition/Processing Equipment

evacuated to about 1 psia. The tank was then repressurized to a total of 16.5 psia with the desired gas constituents using the calculated partial pressure for each gas. The gases were assumed to behave in accordance with the Ideal Gas Law. Bomb samples were taken on those tests measuring the propane/air combustion response. The tank was vented to allow the pressure to return to ambient and then sealed again prior to test. All valves to control the process were operated electrically. Electrically conductive grid paper that marked the magnetic tape at the instant of projectile impact was placed on the entrance plate.

4. SPECIMEN PREPARATION

The foil supplied to the U.S. Army was fanfolded into several sections and installed as shown in Figure 14 and 15. One set of batts was used for each test which fit the tank precisely and therefore the edges of the batts did not need trimming. After installation into the test article the 1.5 mil foil had settled due to the lack of strength from the size of the batts leaving approximately a gap of 1 inch near the top.

5. TEST RESULTS

a. General Discussion

The combustion of a propane/air mixture in a rigid tank should result in a constant volume deflagration. Theory predicts that during such a reaction the pressure is uniform throughout the container. A quick review of the pressure data obtained during these tests revealed that uniform pressures were not measured. Combustion and flammability test results are highly dependent on the test apparatus and ignition source. Some of the ignition source characteristics which caused different readings between transducers on any given tests were: (1) the ignition source itself was large relative to the tank size and moved from one end of the tank to the other, (2) fragments released during projectile detonation impacted the tank wall generating additional localized ignition sites and (3) the incendiary particles released by the HEI-T were scattered

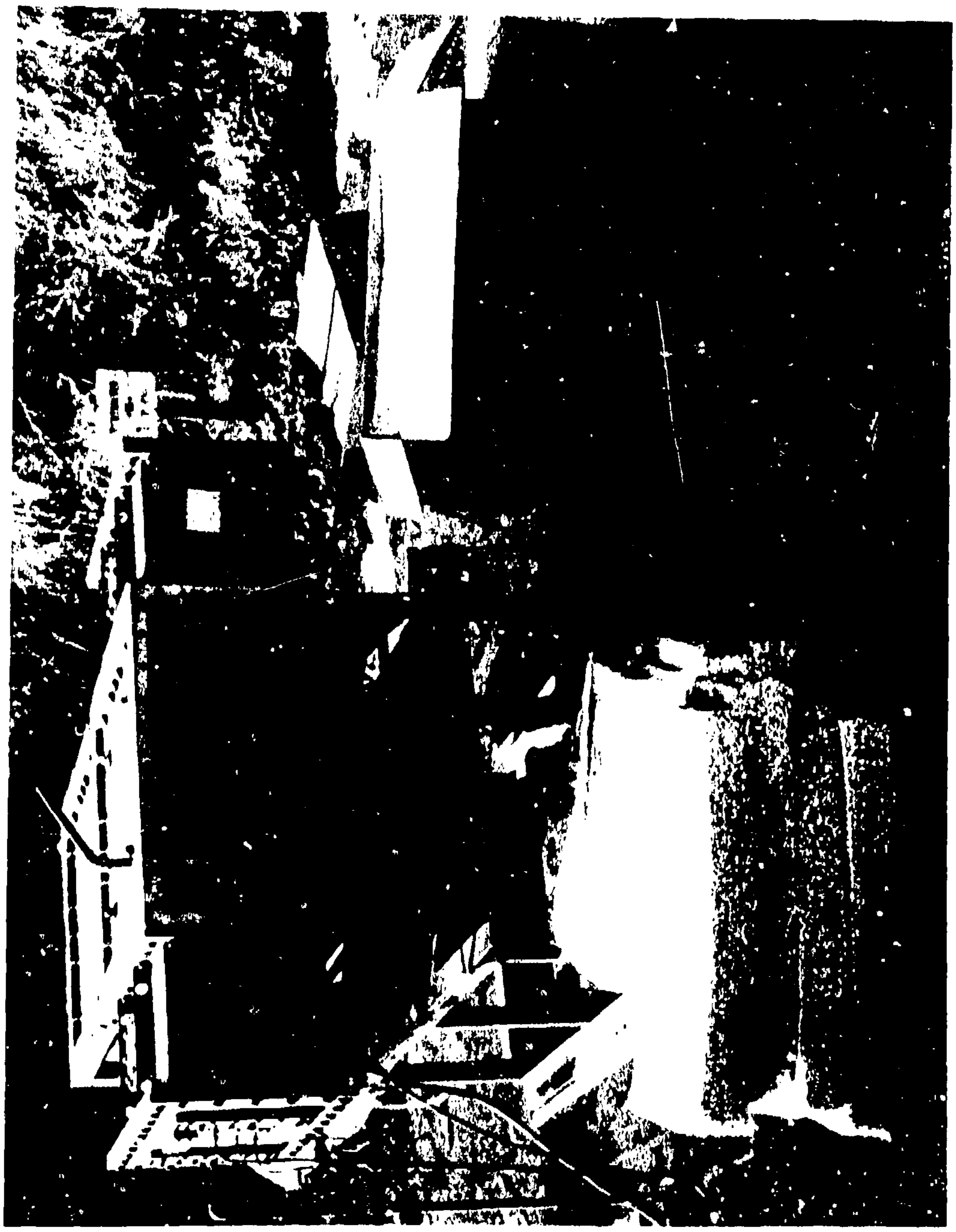


Figure 14. Installation of the Ballistic Test Article—Volume of 40.24 Cubic Feet

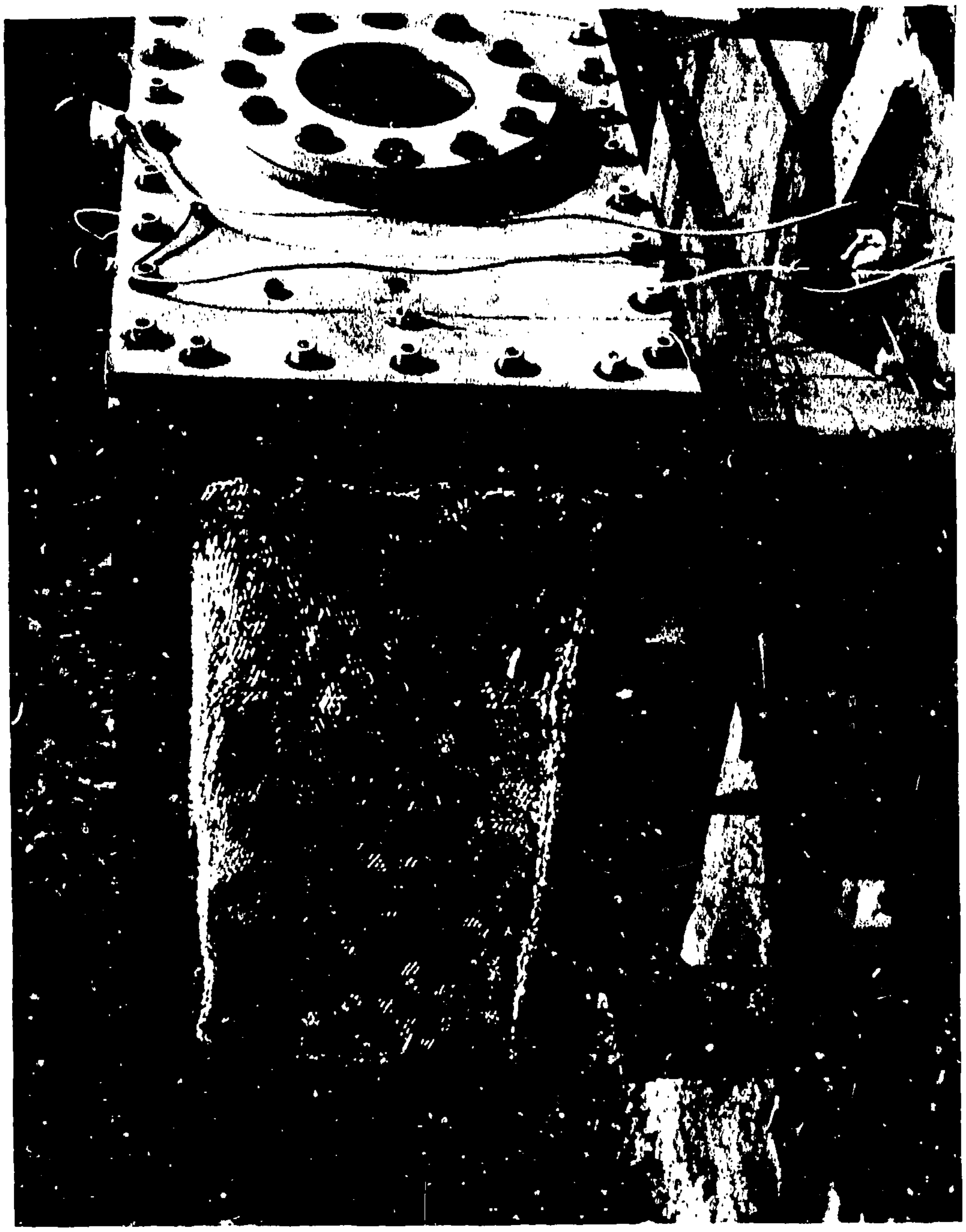


Figure 15. Installation of the Ballistic Test Article - Volume of 15.55 Cubic Feet

throughout the tank and persisted for about one second. In short, during the incendiary ignition event the combustion of the gas mixture did not depend on flame front propagation. Because of this complex event and the rigid nature of the tank, it was not possible to determine the precise location and direction of pressure wave fronts or their reflections and corresponding influence on the pressure at specific transducer locations.

In spite of these factors which resulted in pressure variance between transducer locations, the relative magnitude of the pressure measurements was somewhat predictable. The transducers located closest to the projectile entrance generally recorded a higher pressure than those farther away and the transducer oriented to record reflected pressure during HEI-T tests measured the highest pressures.

When the filler materials were installed in a gross voided configuration some transducers were in a voided area and some were in a filler area. This factor did not noticeably change the relative magnitude of the transducer measurements.

b. Baseline HEI-T and API Results

The purpose of the baseline was to determine the worst case propane/air mixture response to the 23mm HEI-T and .30 cal API. Test data is given in Appendix C. The maximum results were used in the testing of the Explosafe and foam materials. The 23mm HEI-T tests show that the maximum peak combustion overpressure and maximum impulse occur at 4.0 volume percent propane. The .30 cal API tests show that the maximum occurs at 4.5 volume percent.

c. Tests of Explosafe and Blue Foam Using 23mm HEI-T

Tabular summaries of the test results in all tank volumes are given in Appendix C.

(1) Tank Volume of 40.25 Cubic Feet

These results are shown in bar chart form in Figure 16. The pressures follow the same trends as those in the smaller tank, however, the magnitude of the pressures obtained in the larger tank at 40% void is somewhat less than those obtained in the 15.55 cubic foot tank.

(2) Tank Volume of 15.55 Cubic Feet

These results are shown in bar chart form in Figure 17. When the tank was filled with reticulated polyurethane foam (RPF) or Explosafe the combustion pressure was generally less than 10 psig. The pressures increased somewhat during testing of the 40% void at the rear of the tank and increased even more during testing of the 40% void at the front of the tank.

(3) Tank Volume of 29.93 Cubic Feet

This testing involved only the 2.0 mil foil but the voiding varied from 7.6% to 27%. The 12 and 15% voided tests resulted in overpressures less than 10 psig while the 7.6% voided test showed slightly more than 10 psig.

(4) Damage to Explosafe and Blue Foam

Figure 18 shows a typical reaction just after a projectile hit. Figure 19 to 23 show the damage inflicted to filler materials in a 4% fuel to air concentration from a 23mm HEI-T projectile hit. When comparing the Explosafe foil thicknesses, Figure 19 shows that the 1.5 mil foil has much more foil breakdown than the 2.0 and 3.0 mil foil in Figure 20 and 21. Figure 22 shows the damage to the coarse pore blue polyurethane foam. Figure 23 shows that the damage to the 3.0 mil is comparable to the foam damage and the 2.0 mil foil damage is slightly more.

d. Tests of Explosafe Using Caliber .30 Incendiary M-1

These tests were performed to observe the performance of Explosafe as an explosion suppression material when an incendiary projectile

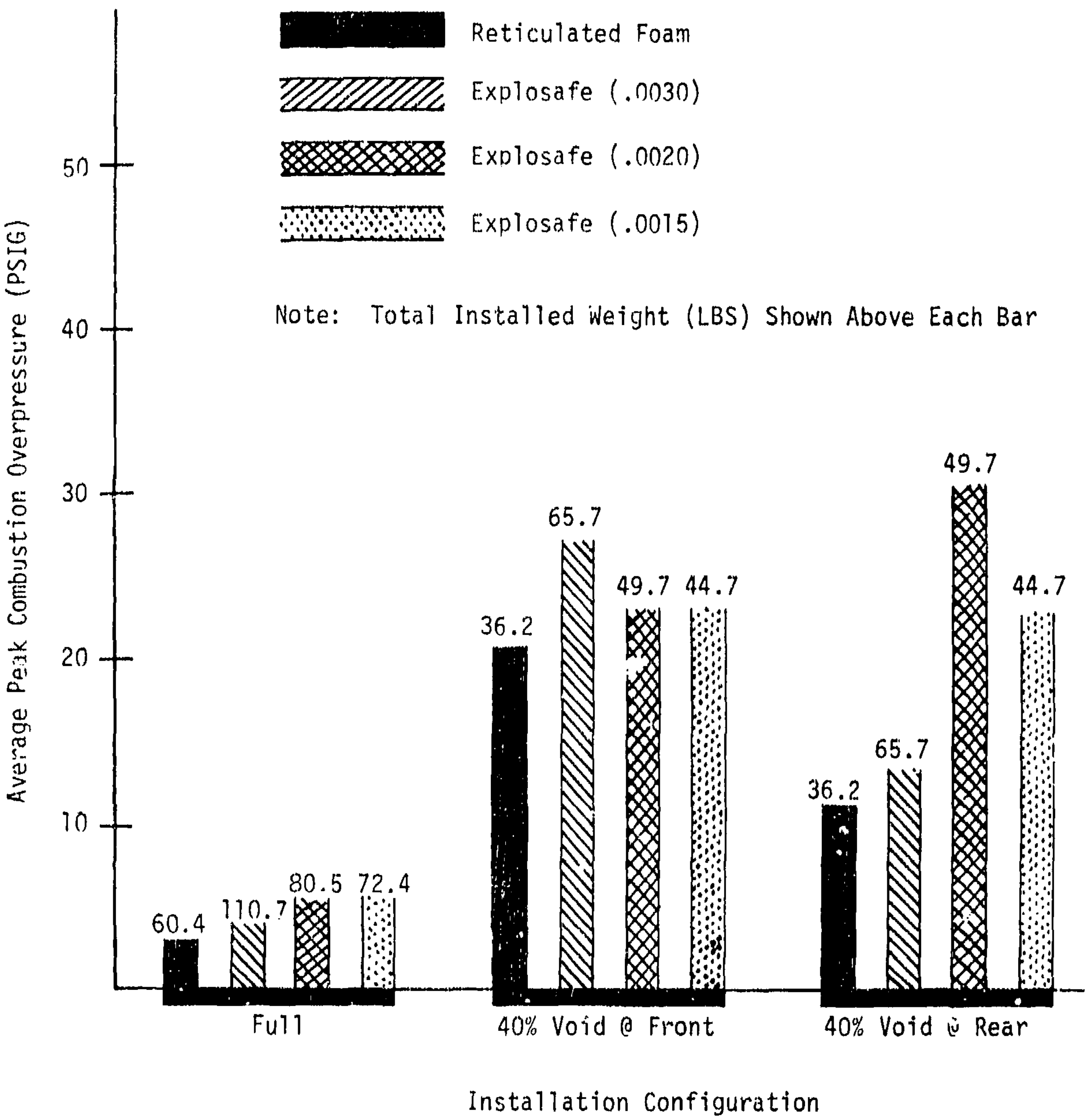


Figure 16. Comparison of the Effectiveness of Various Void Filler Materials in Reducing Peak Combustion Overpressure of Propane/Air Mixtures Initiated by the 23mm HEI-T. Test Data Volume = 40.24 Cubic Feet

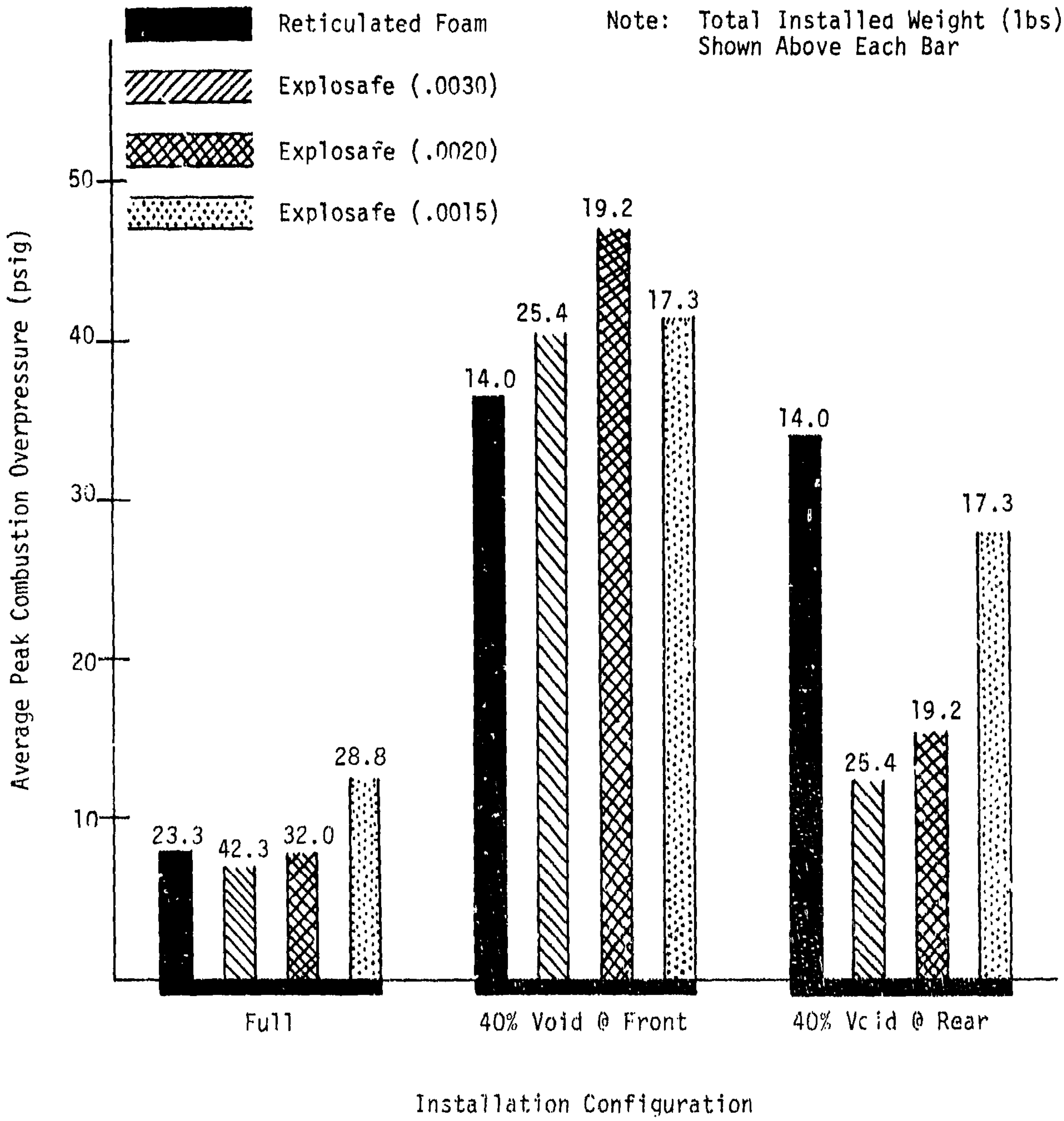


Figure 17. Comparison of the Effectiveness of Various Void Filler Materials in Reducing Peak Combustion Overpressure of Propane/Air Mixtures Initiated by the 23mm HEI-T. Tank Volume = 15.55 Cubic Feet

Figure 18. Typical Reaction of a Projectile Hit

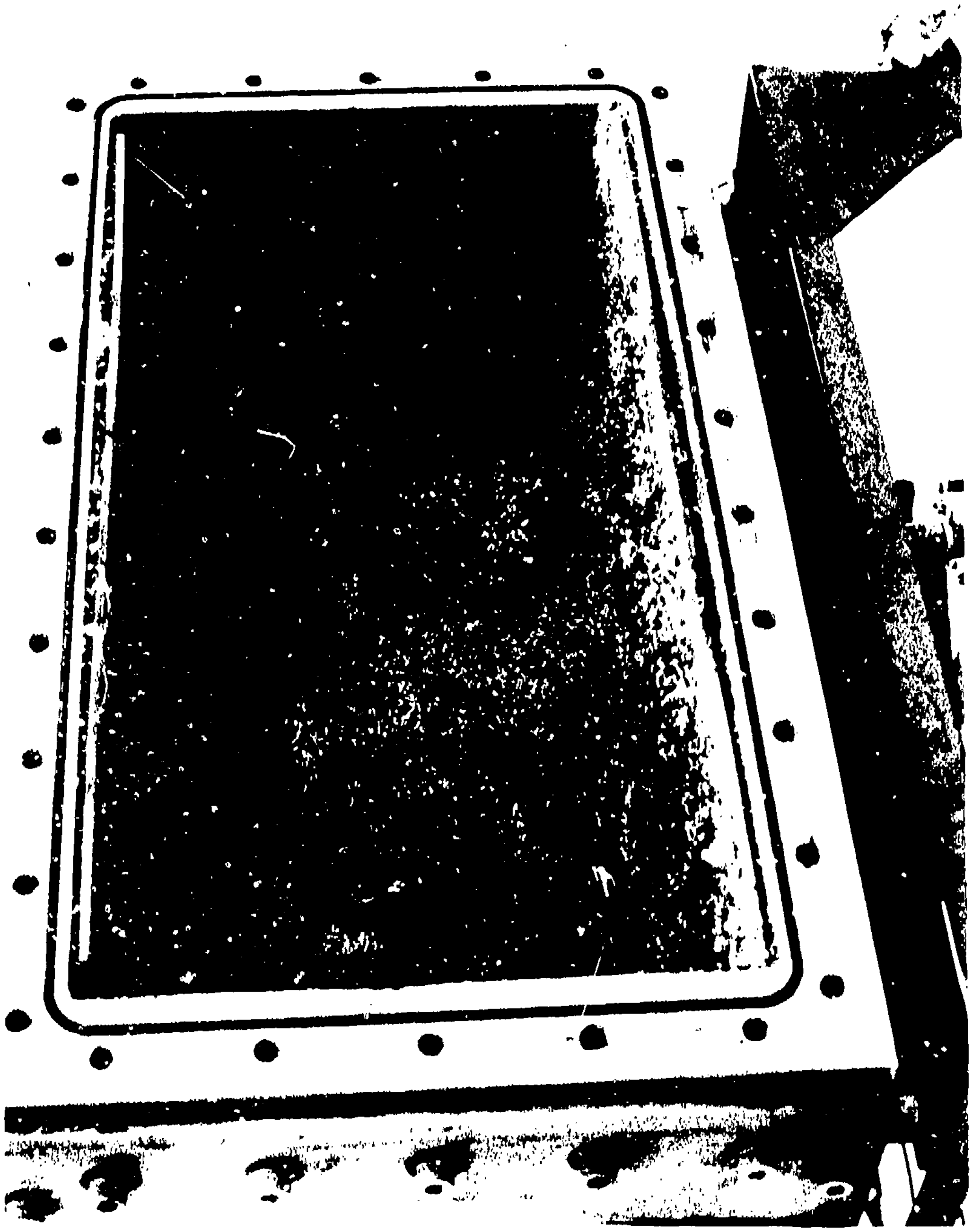


Figure 19. Damage to the 1.5 mil Thick Explosafe After a Typical 23mm HEI-T Projectile Hit

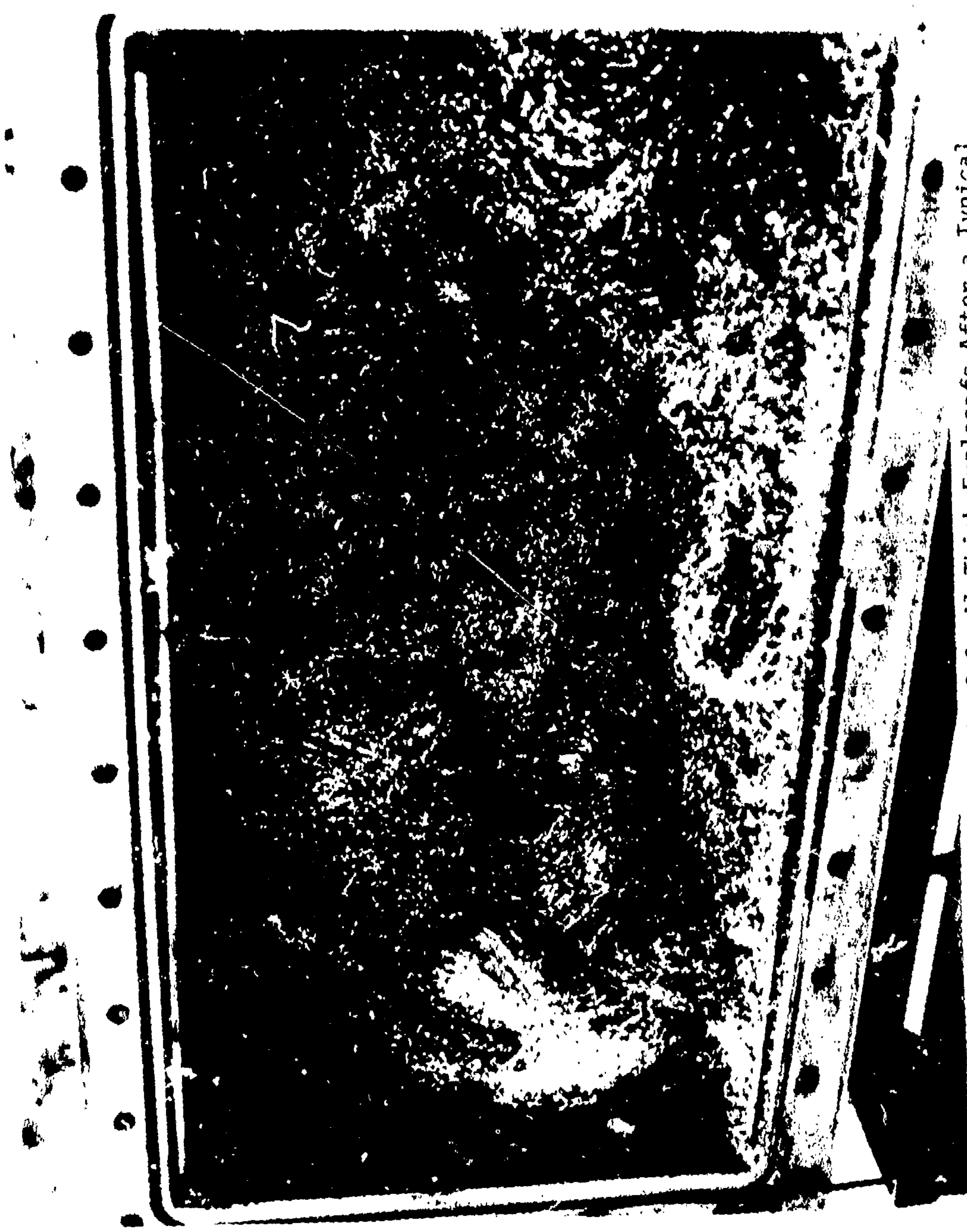


Figure 20. Damage to the 2.0 mil Thick Explosafe After a Typical 23mm HEI-T Projectile Hit

Figure 21. Damage to the 3.0 mil Thick Explosafe After a Typical 23mm *HEI-T Projectile Hit*

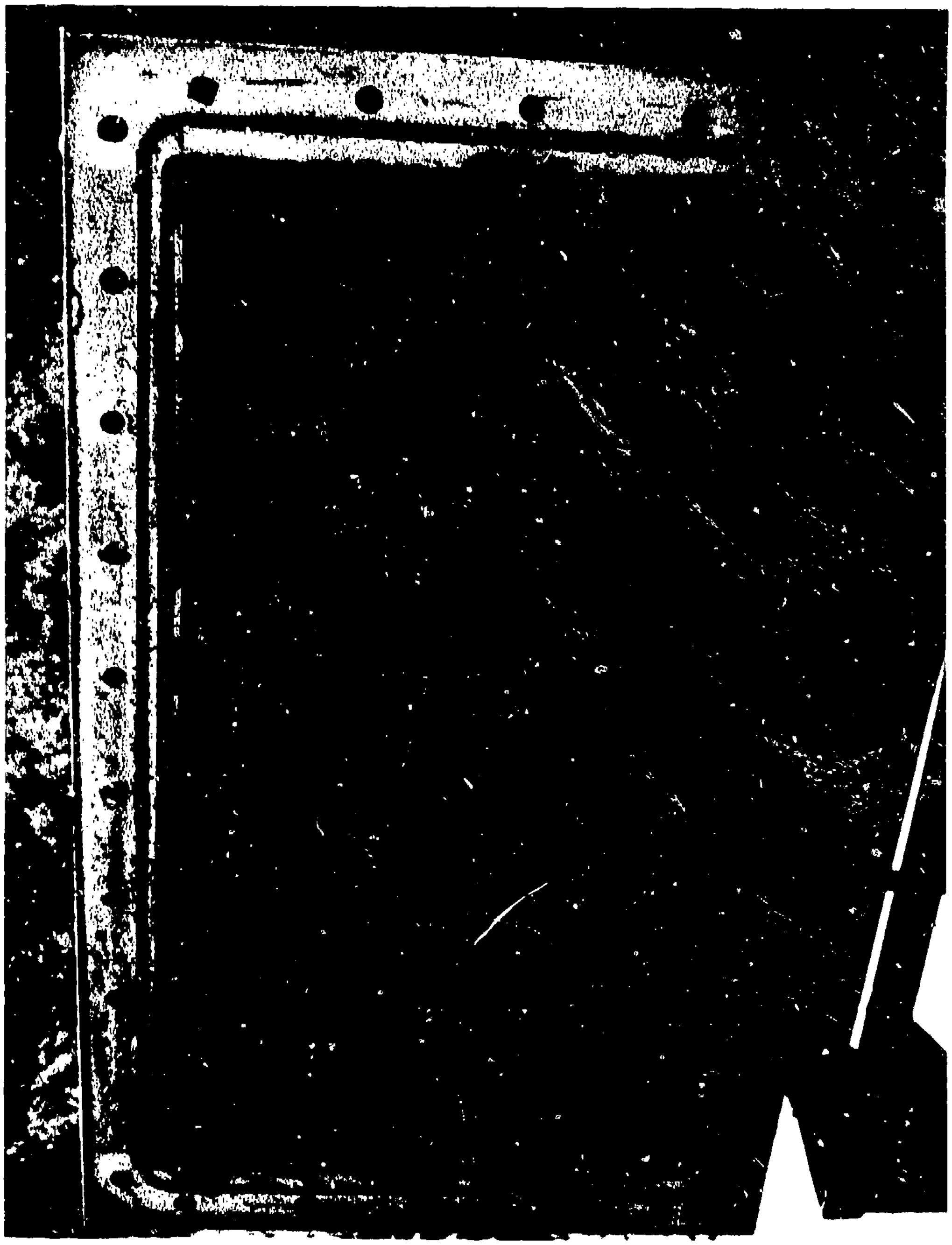


Figure 22. Damage to the Coarse Pore Blue Foam After a Typical 23mm HEI-T Projectile Hit

Figure 23. Comparison of Damage to the 2.0 mil Thick Explosafe, the Coarse Pore Blue Foam and the 3.0 mil Thick Explosafe after a Typical 23mm HEI-T Projectile Hit

is the ignition source. The testing was conducted with 1.5 and 2.0 mil Explosafe and the results are summarized in Appendix C, Table C-6. The results were not plotted in graph form because the trends are clearly evident in the tabular summary. In general the combustion pressure attenuations achieved are higher than those achieved with the HEI-T. Pressures measured in the front voided configuration resulted in very low pressures. This suggests that the location of incendiary activation in small grossly voided configurations may be a significant factor in determining the peak combustion pressure.

6. CONCLUSIONS

The performance of the Explosafe at all three foil thicknesses and of the coarse pore blue foam is within a comparable range in a fully packed configuration and the combustion overpressures usually remained below 10 psig. In general the combustion overpressures increased with increased tank volume. Also, the 1.5 mil Explosafe shows the largest increase in overpressure when the volume is increased. The results at the 40% (by volume) void configuration shows a large amount of data scatter based on where the material is placed in the test article.

The 3.0 mil foil had comparable damage to the foam after an HEI-T projectile hit. The damage to the 2.0 mil foil was slightly worse and the 1.5 mil foil was substantially worse. The damage to the 2.0 mil foil after an API projectile hit was comparable to the foam damage.

APPENDIX A

PROPERTIES OF EXPLOSAFE

SECTION I

MATERIAL DESCRIPTION

The properties and composition of the Explosafe material are given in Table A-1. Explosafe batts are produced in three steps: slitting, expanding, and batt formation (Reference 22). A sheet of aluminum alloy 14" wide is first run through rotary slitting knives. The slitting pattern is shown in Figure A-1a, with dimension C being parallel to the foil width. The foil thicknesses used for this evaluation were 1.5, 2.0 and 3.0 mil. The second step in the production is expansion by gripping the foil between diverging arms and advancing the foil along them. The final expanded foil width is determined by the rate of divergence of the arms and is measured in inches from edge to edge. Figure A-1b shows the result of the expansion, but for clarity the strand twist is not shown. For this testing the expansion varied from 32 to 44 inches. Batt formation is the final production step. The expanded foil can be either rolled up into cylindrical shapes, or fanfolded into cubic shapes, as shown schematically in Figure A-2. The batts are trimmed by an electric knife with special blades to fit the geometry of a particular fuel tank.

TABLE A-1

RAW MATERIAL SPECIFICATIONS

Alloy		AA 3003/AMS 4010
Temper		H24
Thickness		.0015 to .003 Inch
Tensile Strength		20,000 to 23,000 psi
Elongation in 2 Inches		2% to 6%
Melting Temperature		1170°F
Chemical Composition (%)	Minimum	Maximum
Silicon	--	0.6
Iron	--	0.7
Copper	0.05	0.20
Manganese	1.0	1.5
Zinc	--	0.10
Others	--	0.15
Aluminum	Remainder	

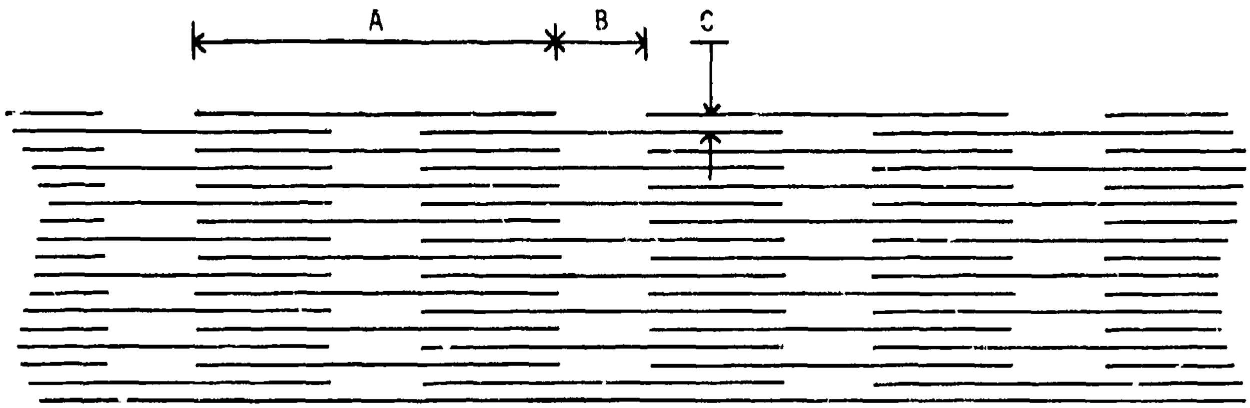


Figure 1a. Slitted Foil

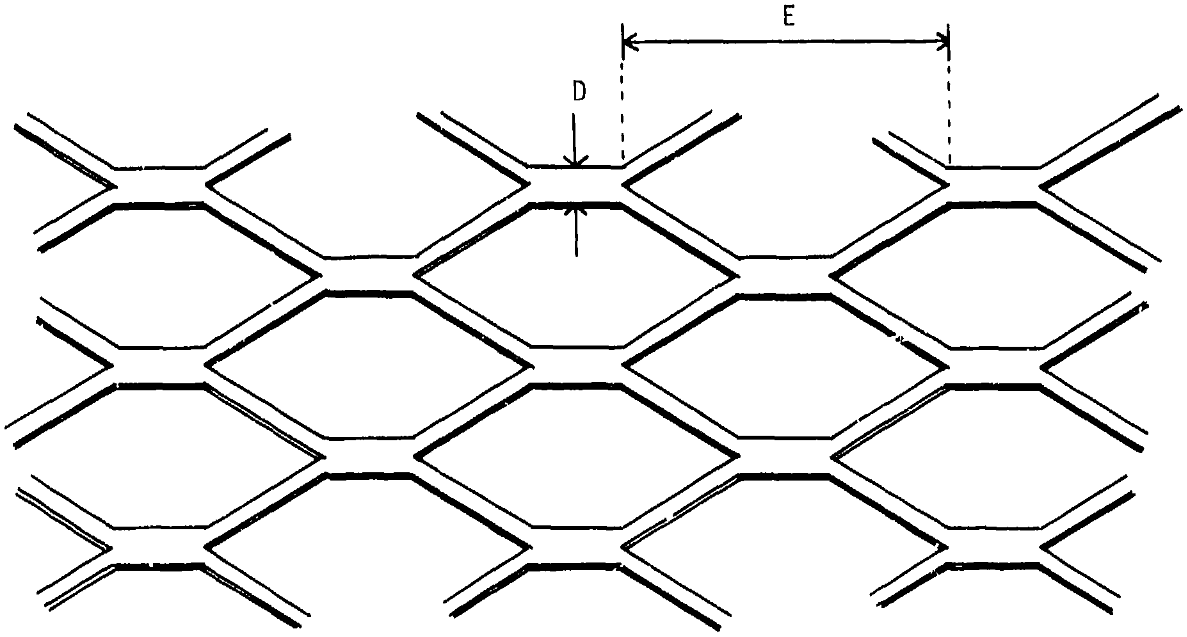


Figure 1b. Expanded Foil

A. Length of Slit

B. Bond Length

C. Strand Width

D. Bond Width

E. Long Dimension of Diamond

Figure A-1. Production Slitting and Expanding

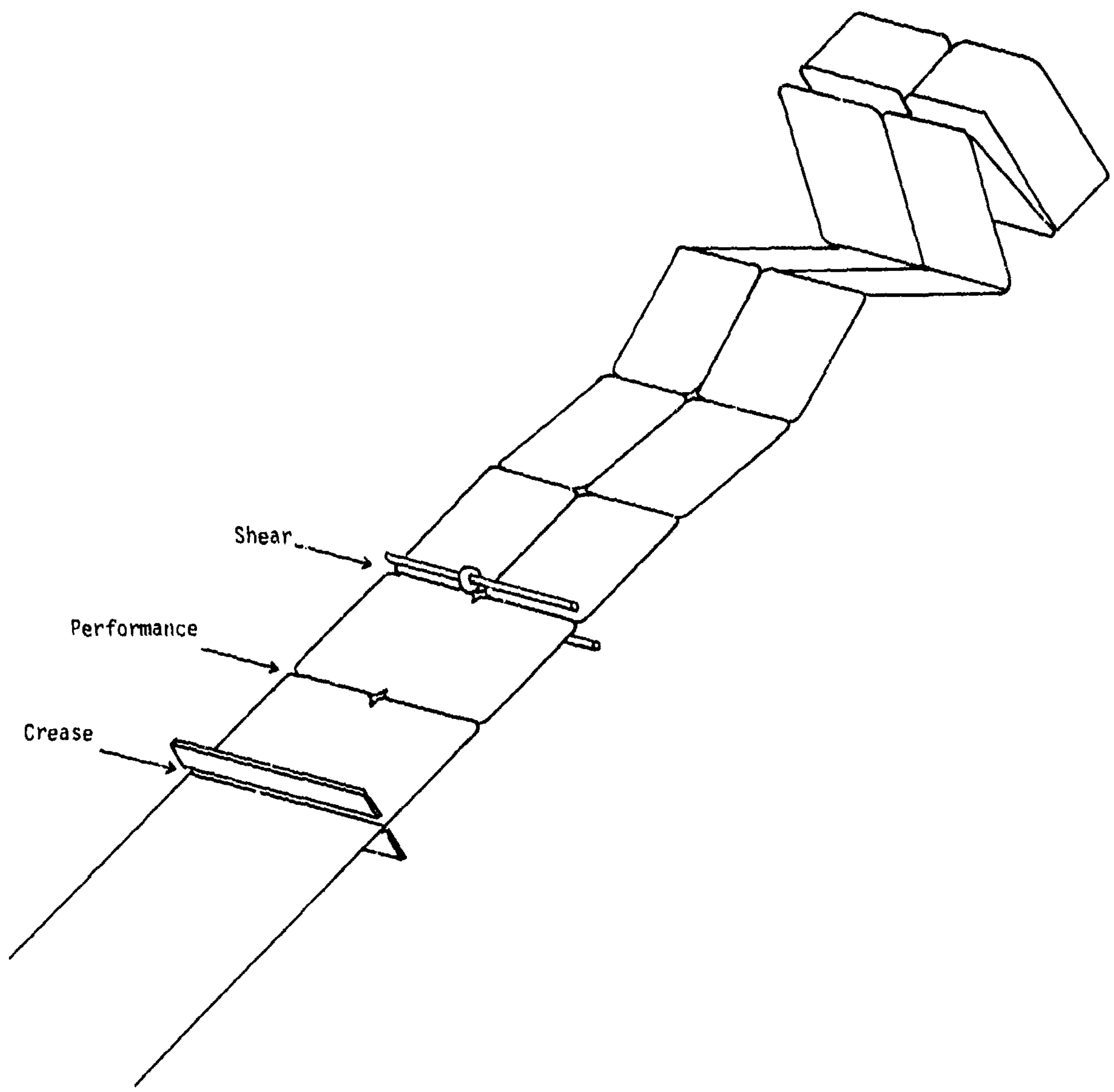


Figure A-2. Batt Formation

SECTION II

ORIENTATION

Orientation refers to the relationship of the foil structure to the direction of flame propagation. Figure A-3 shows three different structures and projected surface areas that could be presented to an advancing flame front. Testing was planned to compare the ability of these orientations to suppress a combustion overpressure. The S-32 orientation has the plane of the diamond parallel to the flame path with the long dimension of the diamond perpendicular to the length of the flame tube. The S-33 orientation has the plane and the long dimension of the diamond perpendicular to the flame path and to the length of the flame tube. The S-34 orientation has the plane and the long dimension of the diamond parallel to the flame path. The long dimension of the diamond is determined by the length of the slit and the amount of expansion (see Figure A-1).

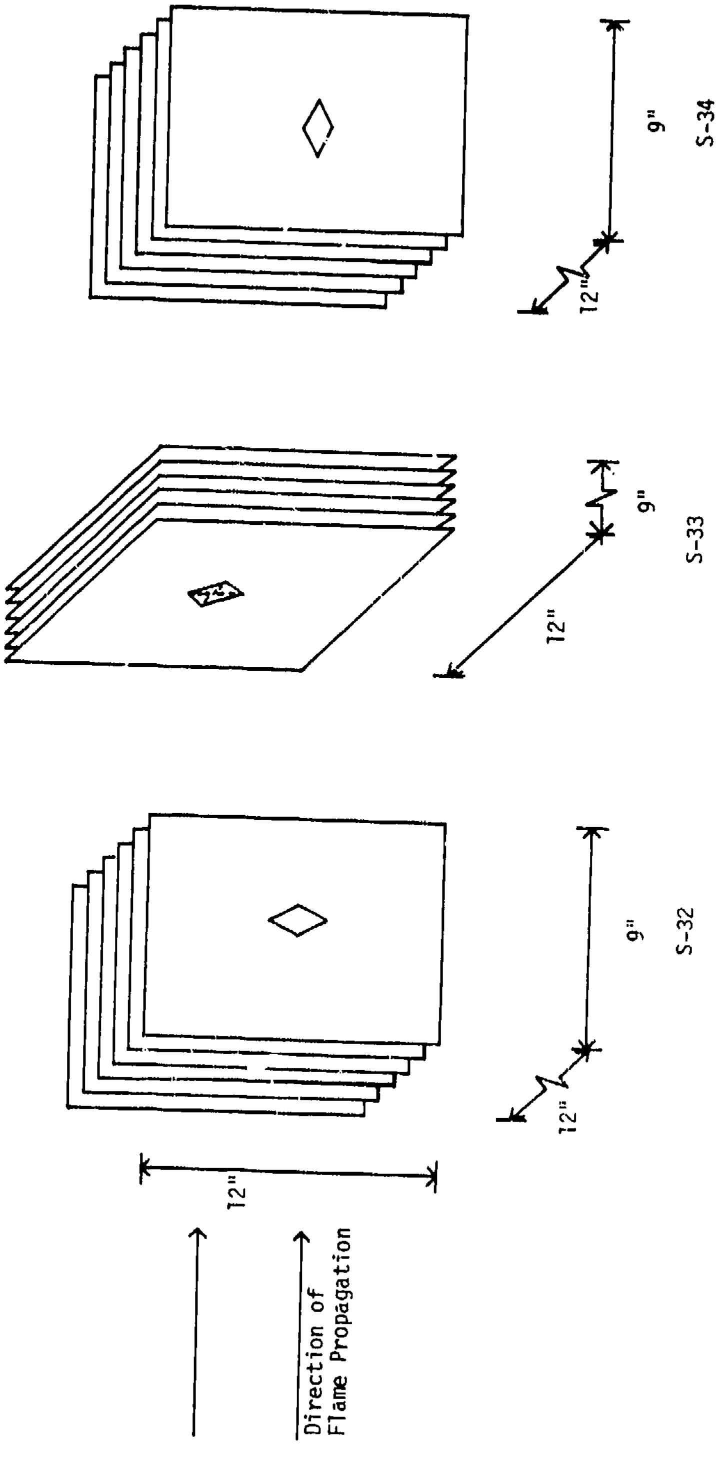


Figure A-3. Orientation Planes

SECTION III

DENSITY

The density of a single layer can be controlled during the fabrication process by varying the material's thickness and expansion width. The weight per unit volume at a given thickness and expansion width is then controlled by the number of cells per inch and the number of layers per inch. The values in Table A-2 give the range of densities used in the flame tube tests and are plotted in Figure A-4. These plots show that the density can be decreased by reducing the material thickness at a constant expansion width or by increasing the expansion width at a constant thickness. The solid lines in Figure A-4b for the 2.0 and 3.0 mil thick material show the average of the densities that VIPL obtained for the various expansion widths (Reference 23 and 24).

TABLE A-2

DENSITY VERSUS EXPANSION AND THICKNESS

Expansion (Inches)	Density (lbs/ft^3) Thickness (mil) 1.5	2.0	3.0
32	1.75	2.33	3.54
35	(1.55)	2.17	(3.23)
38	1.46	(2.03)	2.75
44	(∿1.20)	1.58	2.33

TABLE A-3

SURFACE AREA VERSUS EXPANSION AND THICKNESS

Expansion (Inches)	Surface Area (ft^2/ft^3) Thickness (mil) 1.5	2.0	3.0
32	166.3	166.0	168.2
35	(151.5)	154.6	(151.5)
38	138.6	(136.2)	130.6
44	(113.5)	112.6	110.5

NOTE: Values in () are theoretical values (Reference 16 and 17)

Figure A–4a. Density vs. Thickness

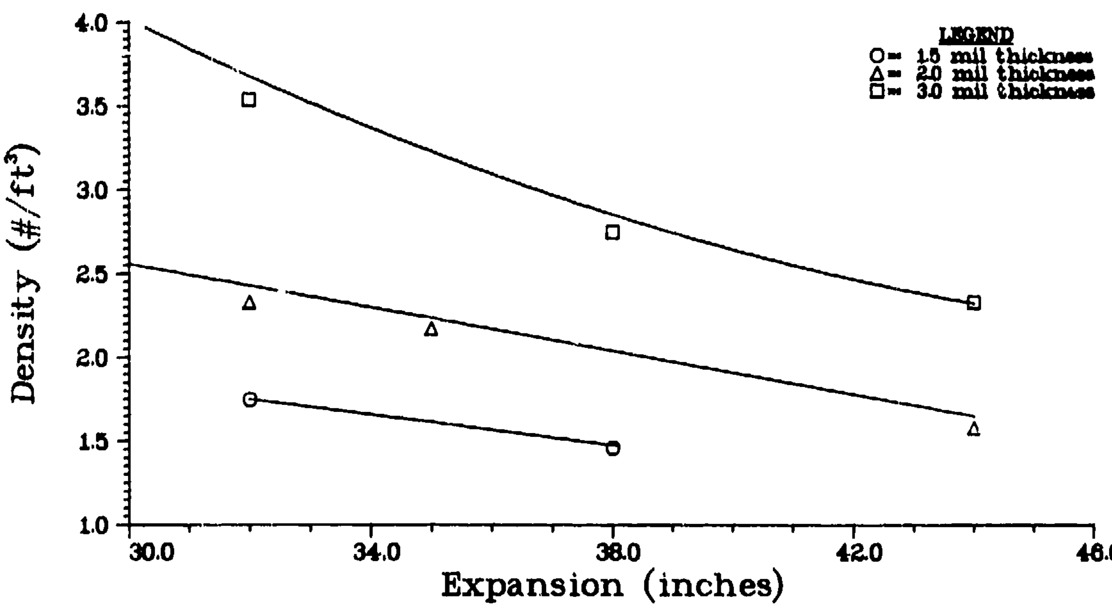


Figure A–4b. Density vs. Expansion

Figure A-4. Density Versus Thickness and Expansion

SECTION IV

SURFACE AREA

The surface area per unit volume (ft^2/ft^3) is a function of the expansion width when the packing density (layers/inch) and other parameters used in slitting the foil are held constant. As shown in Table A-3 the surface area of each thickness varies with the expansion width but varies only slightly between the thicknesses at a given expansion. In calculating the surface area the thickness is not considered since there is negligible gain in surface area due to the thinness of the material. Figure A-5 shows an average of surface area versus expansion (Reference 23) and the data points from Table A-3. The surface area decreases with an increase in expansion.

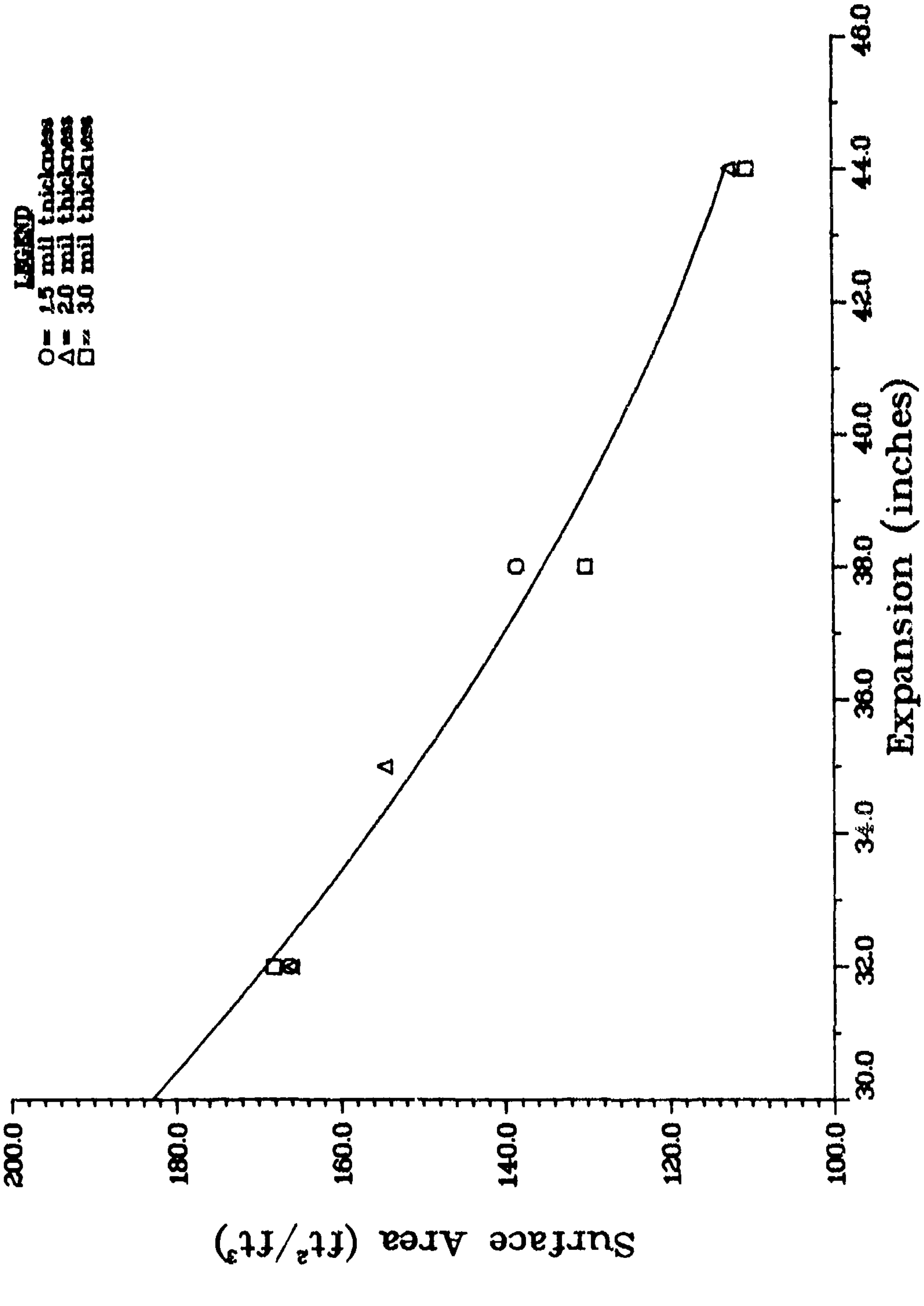


Figure A-5. Surface Area Versus Expansion

APPENDIX B

FLAME TUBE TEST DATA

SECTION I

TEST EQUIPMENT - AFWAL/PO FLAME TUBE SET-UP

The test chamber, called the flame tube, consists of a rectangular stainless steel tank capable of containing combustion overpressures as high as 120 psig. This tank was constructed under AFAPL Contract F33601-71-C-0130 with Systems Research Laboratory, Inc. (SRL), Dayton OH. The exact dimensions of the rig are contained in the SRL engineering drawings, numbers 7507-22-1530 through 7507-22-1538. A schematic of the test rig is shown in Figure B-1. The tank is constructed such that it can be opened at each end and dismantled into three sections, each 30 inches in length. The rail system on the supporting stand enables the two end sections to be rolled 29 inches away from the mid section. The inside dimensions of the flame tube measure 12 x 12 x 90 inches. Six, 8 inch plexiglass windows, 2 in each section, are used to observe ignition and flame propagation.

Figure B-2 shows a schematic diagram of the test equipment used to conduct the testing. The location of the ports used for the test equipment are lettered for reference.

Testing was done with propane to air mixtures. After the tank was vacuumed to a low pressure a specified concentration of propane and air was injected into the tank at location I. A circulation pump was used to provide a uniform mixture by pulling the mixture from the tank at position L and returning it to position C. The ambient temperature of the fuel/air mixture was recorded prior to each test by use of a copper constantan thermocouple in position D. An Ashcroft 0-50 psia pressure gage was used to mix the concentration of propane to air by partial pressures. It was also used to set the initial pressure prior to testing, and to make a quick calibration check on the pressure transducers.

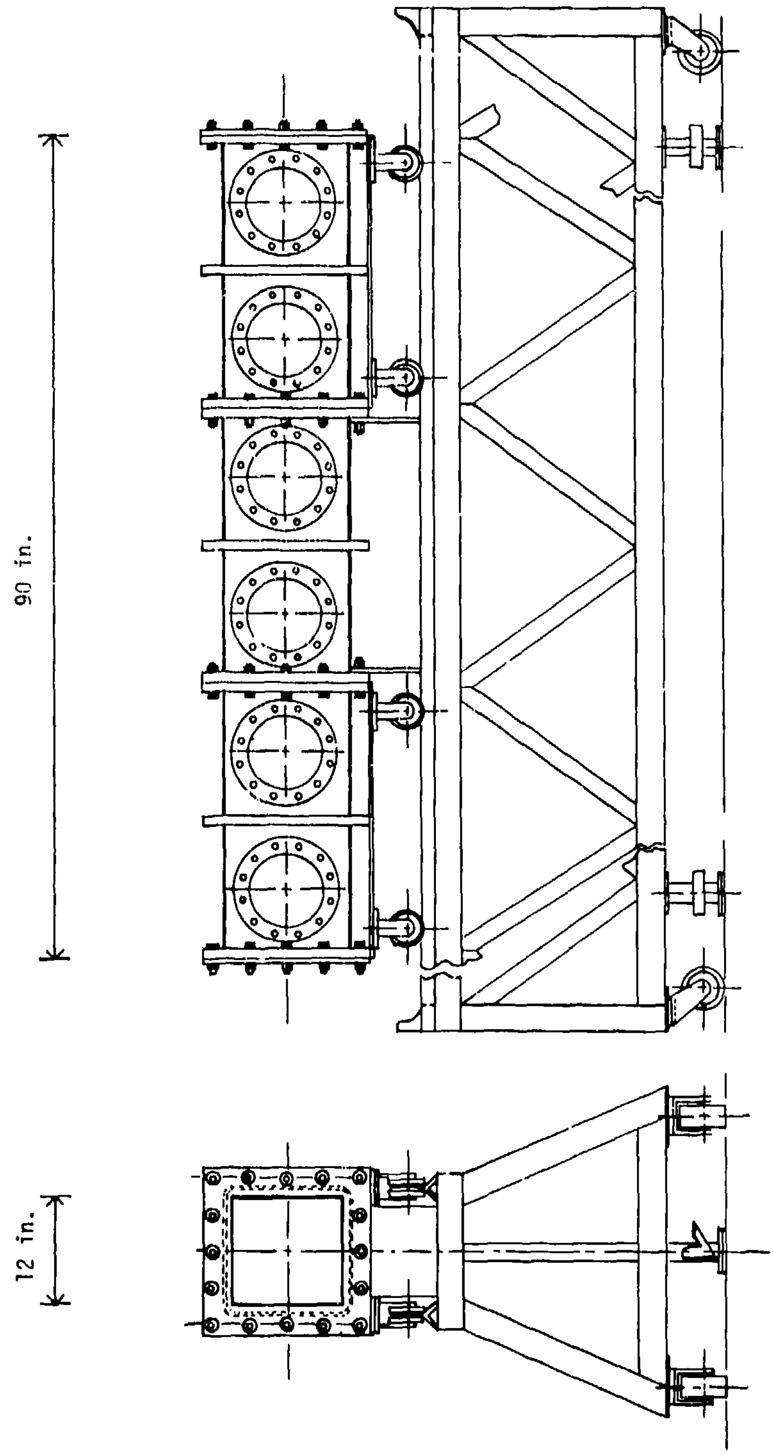


Figure B-1. AFWAL/PO Flame Tube Schematic

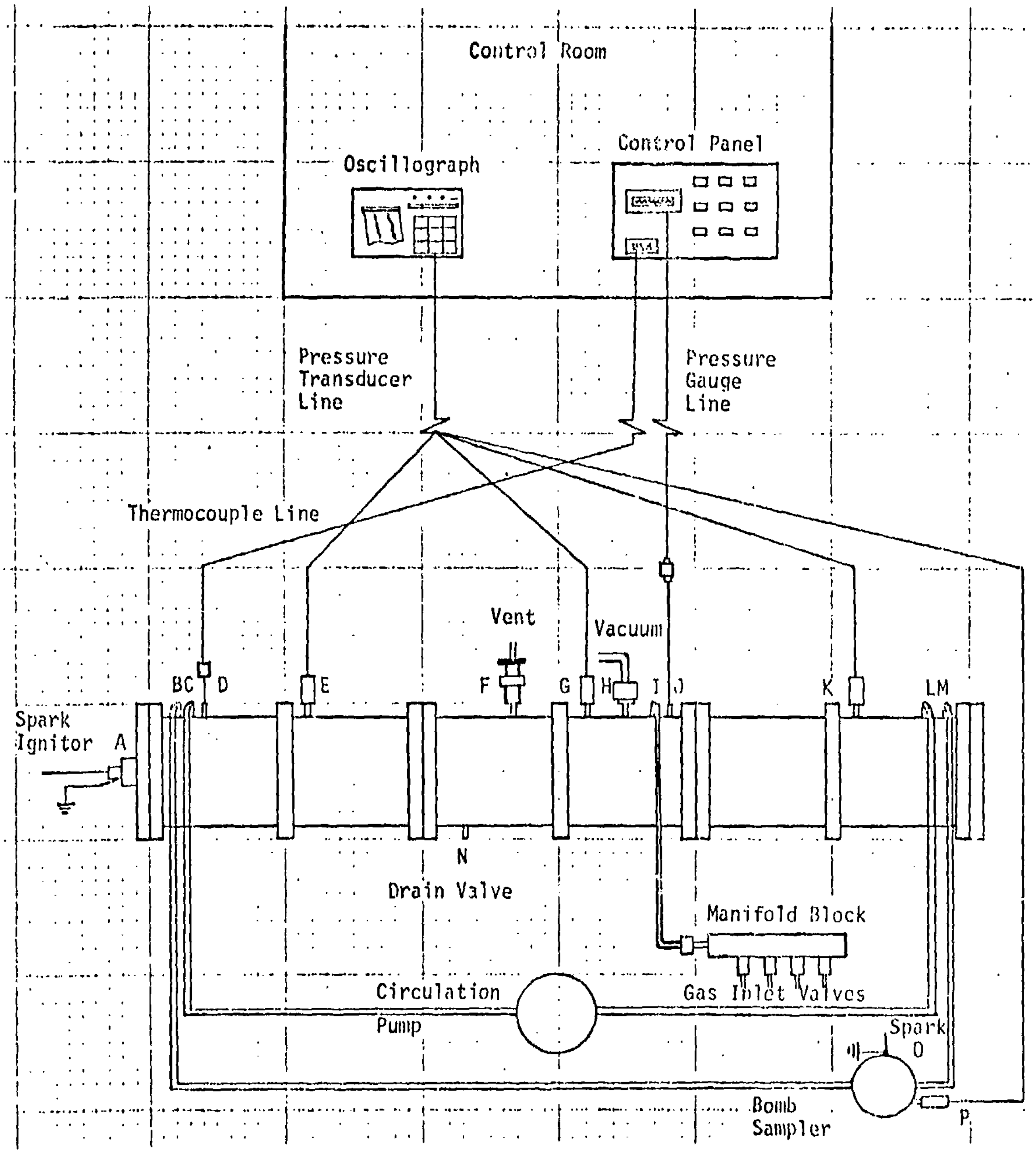
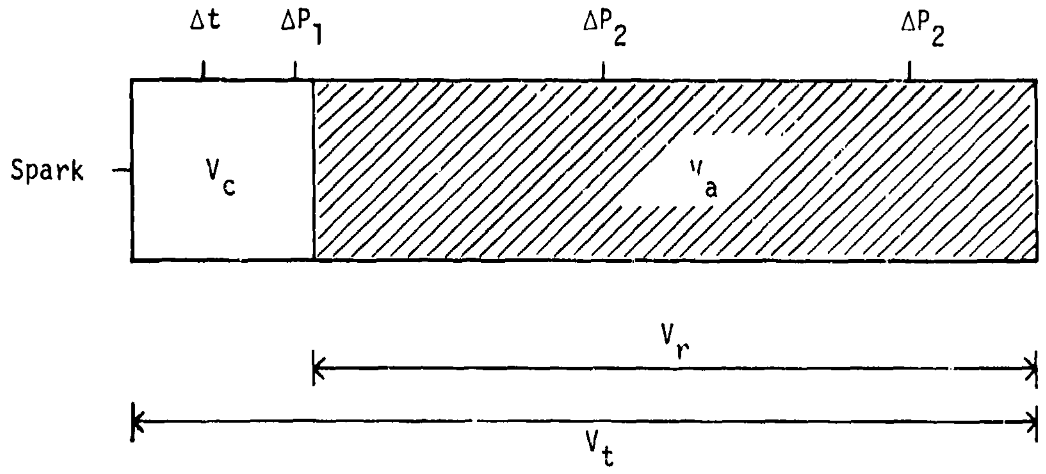


Figure B-2. Schematic Diagram of Flame Tube Test Equipment

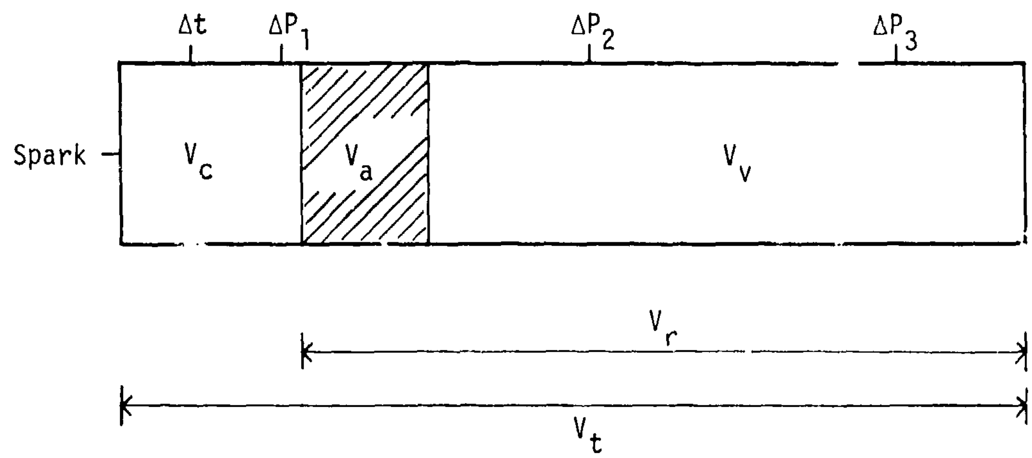
The spark ignitor, located in position A, consisted of a stainless steel-sheathed copper electrode with a 0.1 inch gap. This electrode was electrically isolated from the tank with teflon. A similar electrode was mounted in the bomb sample bottle, position O. Both electrodes used the same ignition source by using an electric motor to move a contact point from one position to the other. A 0.02μf capacitor was charged to 12,000 volts and discharged through the electrodes. A black and white RCA camera and video system were used to record the ignition and flame propagation through the tank.

Combustion overpressures were measured with CEC 0-150 psia strain gage pressure transducers, calibrated with a dead weight tester to 100 psia. The overpressure results are identified in the data tables as ΔP_1, ΔP_2 and ΔP_3 corresponding to their positions at locations E, G and K respectively. A third pressure transducer was mounted in the bomb sample bottle that was used to verify the proper fuel/air concentration. All the transducers were electrically isolated from the chamber with 1 inch teflon tubing in order to prevent damage to the transducers from the ignition system. The pressure traces were recorded by an oscillograph onto light sensitive paper. During the test series three oscillographs were used: (a) Clevete brush recorder and amplifiers from tests 0 to 40, (b) CEC oscillograph and Natel Model 2088 amplifiers from tests 41 to 109 and (c) Honeywell Model 1858 fiber optics recorder and amplifiers from tests 110 to 150.

The void configurations are defined in Reference 1, MIL-B-83054 and are shown in Figure B-3. V_c is the combustion volume, V_a is the arrestor volume and V_v is the void volume downstream of the arrestor. In the Explosafe testing V_c was varied from approximately 0% (fully packed) to 40% by volume at intervals of 10%. The total relief volume, V_r, is defined as $V_a + V_v$ and the total volume of the tank, V_t, is $V_c + V_r$. When the material being tested performs as a flame arrestor a thickness test is performed to determine the minimum arrestor thickness, T_m, required to prevent flame propagation from V_c to V_r. In the case of the Explosafe material this test was not required since the flame propagated through the material in a fully packed configuration.



3a. Typical Set-Up for Single Void Ignitions



3b. Typical Set-Up for Arrestor Thickness Tests

Figure B-3. Flame Tube Void Configurations

The test execution was accomplished remotely from a control room which enabled actuation of the solenoid and ball valves, the recorder and the ignitor. The basic procedures for these tests were:

a. Install the proper amount of foil.

b. Check instrumentation.

c. Vacuum the tank to a low pressure.

d. Add 5% concentration of propane to air for a pressure greater than the desired initial test pressure.

e. Allow at least 10 minutes of mixing time.

f. Tank bomb samples to verify the concentration.

g. Establish initial test pressure (14.7 or 17.7 psia).

h. Start instrumentation.

i. Ignite the fuel/air mixture.

j. Purge the tank of combustion products before opening.

k. Remove foil for inspection and prepare for next test.

SECTION II

FLAMMABILITY RANGE OF PROPANE IN THE FLAME TUBE

The purpose of this testing was to determine the maximum combustion overpressure obtainable for propane in the AFWAL/PO flame tube. This testing was accomplished under a previous AFWAPL/PO in-house program (Reference 25 and 26). Table B-1 gives the results of this testing and Figure B-4 shows that the maximum average combustion overpressure occurs at 5% by volume concentration of propane in air. The combustion overpressure is recorded as a differential pressure (psid) between the initial pressure before ignition and the average peak pressure during combustion. The Δt is the time from the initiation of the spark to the average peak pressure in seconds. Figure B-5 illustrates the frequency response which occurs in certain pressure ranges associated with various propane/air mixtures. Based on this response the combustion overpressure values in Tables B-4 through B-6 were recorded as a peak overpressure and an average peak overpressure.

TABLE B-1

BASELINE COMBUSTION TESTS IN AFWAL/PO FLAME TUBE

Propane Conc. (Vol. %)	Test No.	Pa (psia)	Ta (°F)	ΔP_2 Average (psid)	Δt_2 (sec)	Remarks
2.0	1	14.31	56	0.0	0.00	Tests 1 to 47 performed October 1975
2.5	13	14.31	70	53.0	1.85	
3.0	2	14.31	56	70.0	0.96	
4.0	3	14.31	58	90.0	0.48	
5.0	12	14.31	69	94.0	0.55	
6.0	4	14.31	61	85.0	0.80	
6.5	47	14.10	66	75.0	1.58	
7.5	14	14.37	62	54.0	4.05	
8.0	7	14.27	63	3.0	3.48	

TABLE B-1a

INITIAL PRESSURE 0 PSIG

2.2	352		65	0.0	0.00	Tests 305 to 354 per- in October 1975 Tests 76-35 to 76-39 performed in December 1976
2.3	344		71	53.0	2.84	
2.5	306A		63	68.0	2.21	
3.0	348		60	80.0	0.52	
3.5	314		74	90.0	0.72	
4.0	76-38	14.14	68	107.0	0.44	
4.1	305		61	106.0	0.43	
4.5	337		72	110.0	0.43	
4.5	75-36	14.28	74	110.0	0.41	
5.0	76-35	14.21	73	111.0	0.28	
5.0	308			113.0	0.44	
5.0	343		67	111.0	0.45	
5.0	349		67	110.0	0.45	
5.5	76-37	14.10	73	107.0	0.40	
5.5	335		67	115.0	0.52	
5.5	354		65	111.0	0.58	
5.8	350		65	98.0	0.44	
6.0	76-39	14.25	70	117.0	0.54	
6.0	309		65	106.0	0.83	
6.5	351		65	85.0	0.94	
7.0	310		68	82.0	2.88	
7.0	345		68	82.0	2.88	
7.5	311		71	8.0	3.34	
7.5	346		75	14.0	4.10	
8.0	353		66	4.0	3.53	
8.1	307A		67	6.0	2.96	
9.0	307		67	0.0	0.00	

TABLE B-1b

INITIAL PRESSURE 3 PSIG

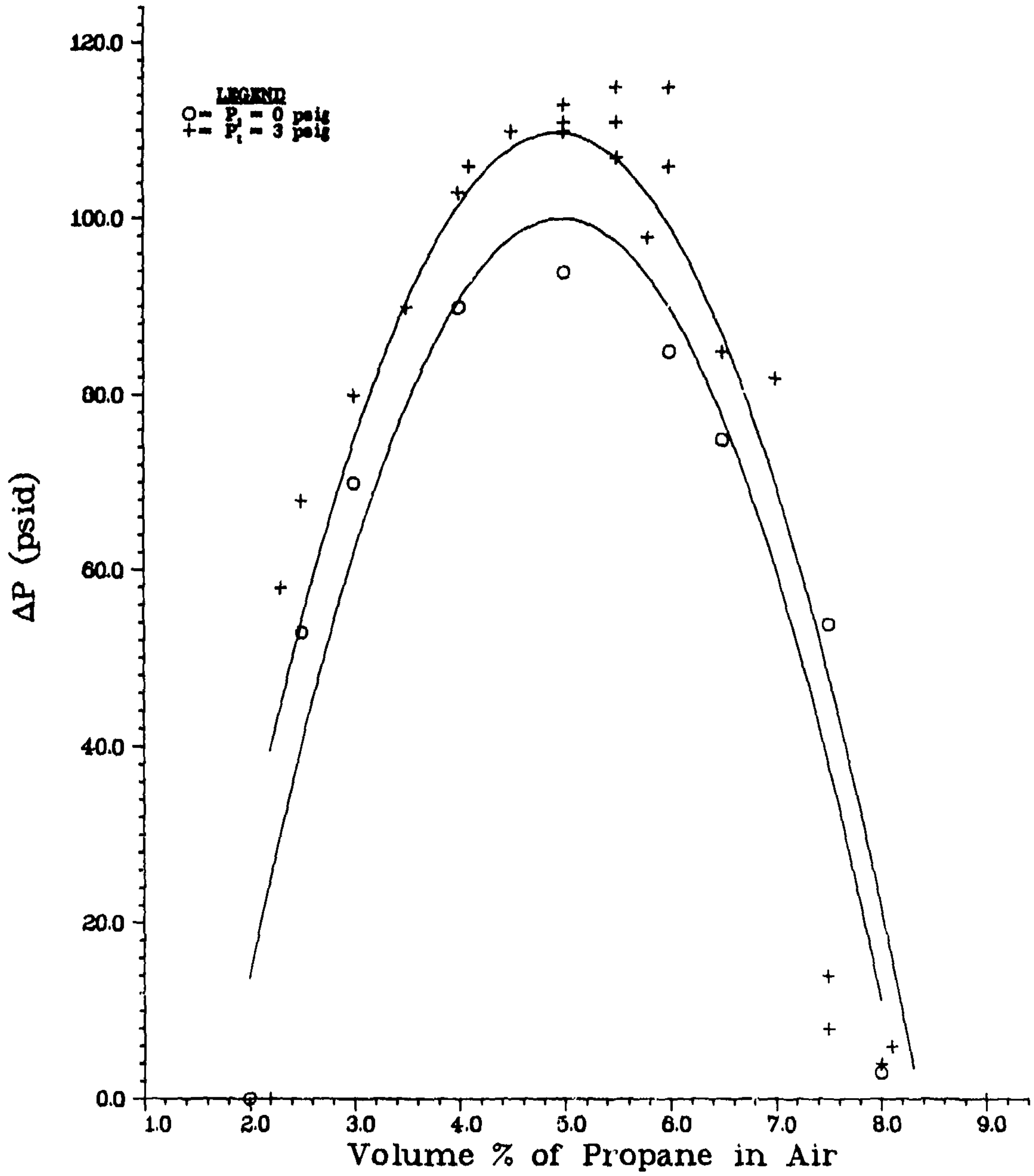
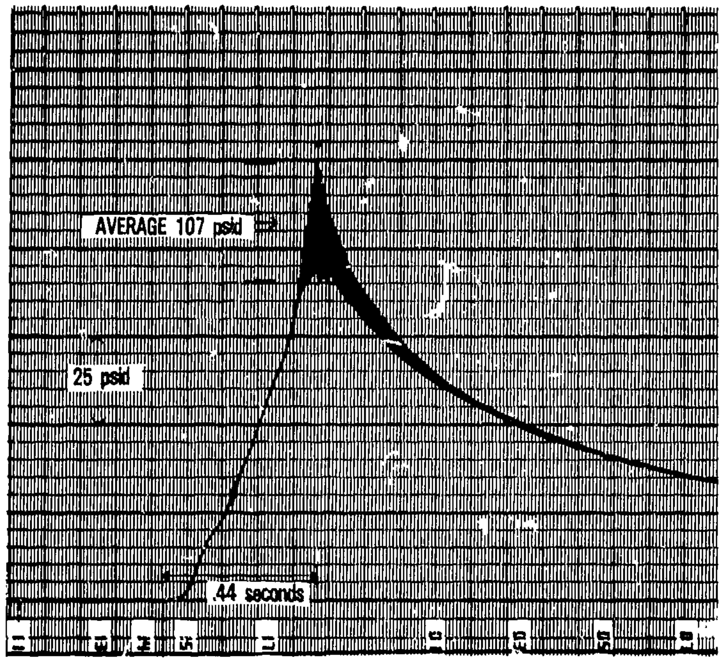
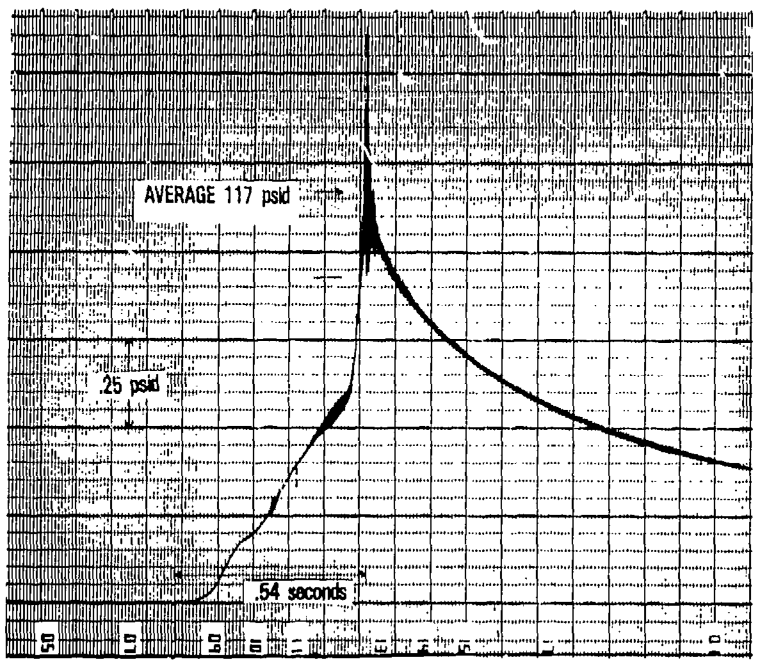


Figure B-4. Flammability of Propane in Air - AFWAL/PO Flame Tube



B-5a. Test 76-38, Initial Pressure 17.14 psia (3 psig), 4% by Volume % Propane in Air



B-5b. Test 76-39, Initial Pressure 17.25 psia (3 psig), 6% by Volume % Propane in Air

Figure B-5. Pressure Traces of Baseline Flame Tube Tests

SECTION III

TEST DATA

1. Preliminary Test Data on Explosafe

Table B-2 consists of the test data generated under the preliminary testing of the 3.0 mil Explosafe in October 1975 (Reference 27). The nominal density was 3.35#/ft^3.

2. Orientation Test Data

The test data for Set II of the orientation study is contained in Table B-3. This testing was done with the 3.0 mil foil at a 38 inch expansion and density of 2.75#/ft^3.

3. 3.0 mil Foil Test Data

Test results on the 3.0 mil foil over a range of densities is given in Table B-4. Note that the test data for the 3.0 mil foil, 38 inch expansion and density of 2.75 is in Table B-3a and B-3d.

4. 2.0 mil Foil Test Data

Test results on the 2.0 mil foil are given in Table B-5.

5. 1.5 mil Foil Test Data

Test results on the 1.5 mil foil are given in Table B-6.

Combustion Void (%)	P_I (psig)	Test No.	Density (lbs/ft^3)	Pa (psia)	Ta (°F)	ΔP_2 (psid)	Δt_2 (sec)	Propane Conc. (Volume %)	Remarks
0.1	0.5	315	3.35	14.30	74	3.0	0.29	5.0	Material installed in a horizontal position in tests 315 through 330.
3.2	0.5	317	3.35	14.28	73	4.0	0.26	4.9	
5.0	0.5	319	3.36	14.26	74	5.0	0.19	4.9	
9.4	0.9	321	3.34	14.24	76	6.0	0.16	5.0	
20.2	0.5	323	3.36	14.24	76	8.0	0.23	5.0	
0.1	3.0	316	3.35	14.28	73	5.0	0.29	5.1	
3.2	3.0	318	3.35	14.27	76	5.0	0.23	4.8	
5.0	3.0	320	3.36	14.25	78	6.0	0.26	5.0	
9.4	3.0	322	3.34	14.24	76	8.0	0.18	5.0	
20.2	3.0	324	3.36	14.36	64	11.5	0.19	5.0	
30.5	3.0	325	3.39	14.36	66	16.0	0.11	5.0	
31.3	3.0	326	3.40	14.36	66	19.0	0.14	5.0	
40.0	3.0	327		14.35	66	24.0	0.13	5.0	Density not recorded.
49.4	3.0	238		14.35	67	37.0	0.12	5.0	Density not recorded.
77.8	3.0	329	3.95	14.24	60	72.5	0.14	4.9	
2.6 (87.0)	3.0	330	3.05	14.21	62	68.0	0.27	5.0	2 Voids; 2.6% at spark end and 87.0% relief volume.
18.6	3.0	331	3.26	14.28	61	10.0	0.12	4.9	Material installed in vertical position, tests 331-334.
39.4	3.0	332	3.28	14.28	63	20.0	0.17	5.0	
50.5	3.0	333	3.28	14.20	65	31.0	0.15	5.0	
73.3	3.0	334	3.40	14.25	66	73.0	0.19	5.0	

Table B-2: Preliminary Testing of Explosafe - October 1975

Combustion Void (%)	Test No.	Ta (°F)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (inches)	Remarks
0	129	70		5.6	0.181		5.6	0.169				NMT	(No Measurement Taken)
10	130	70		7.6	0.229		7.2	0.225				NMT	
20	131	71		10.0	0.074		9.4	0.125				9.0	
30	132	73		16.8	0.130		16.0	0.130				NMT	
40	133	73	25.6	22.4	0.110							15	

Table B-3a: S-32 Orientation; Initial Pressure = 14.7 psia

0	134	75		7.5	0.174		8.0	0.170				6.0	
10	135	78		12.0	0.195		12.0	0,183				---	Batts Moved too Much too Record
20	136	80	16.8	15.5	0,121		14.5	0.125				15	
30	137	75		26.5	0.116		24.5	0.121				12	

Table B-3b: S-32 Orientation; Initial Pressure = 17.7 psia

0	111	73		6.0	0.150					5.6	0.138	0.0	
10	112	75		9.0	0.156				10.6	8.8	0.158	NMT	
20	113	75		11.5	0.133				16.0	12.0	0.121	3.0	
30	114	77		15.3	0.156				17.5	14.5	0.130	6.0	
40	115	78	24.0	23.6	0.135				34.0	24.0	0.130	3.0	

Table B-3c: S-33 Orientation Initial Pressure = 14.7 psia

Table B-3: Test Results of Orientation Study - Set II; 3 mil Foil, 38 inch Expansion, Density = 2.75 #/ft^3

Combustion Void (%)	Test No.	Ta (°F)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Foil Comp. (inches)	Remarks
0	117	74		10.0					14.0	10.0		NMT	
0	123	77		8.1	0.066					10.6	0.070	NMT	
10	124	74		13.0	0.108					15.0	0.108	NMT	
20	125	77	14.0	13.2	0.106	16.0	14.0	0.103				NMT	Right Transducer Moved to Center of Tank
30	121	82		30.0	0.113				31.0	26.0	0.100	NMT	
40	116	79		34.0	0.115				50.8	38.8	0.110	NMT	
40	122	85		37.0	0.113				47.5	41.5	0.103		

Table B-3d: S-33 Orientation; Initial Pressure = 17.7 psia

Combustion Void (%)	Test No.	Ta (°F)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Foil Comp. (inches)	Remarks
0	138	78		5.0	0.151		5.0	0.151				N	(Negligible)
10	139	77		9.5	0.100		9.5	0.100				N	
20	140	77		9.5	0.158		9.5	0.155				0.5	
30	141	77		14.0	0.125							1.5	
40	142	76		21.5	0.125		20.0	0.125				3.0	

Table B-3e: S-34 Orientation; Initial Pressure = 14.7

Combustion Void (%)	Test No.	Ta (°F)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Foil Comp. (inches)	Remarks
0	143	78		8.4	0.090		8.8	0.086				N	
10	144	75		11.5	0.091		11.5	0.090				1.0	
20	145	76		17.8	0.113		18.0	0.108				1.5	
30	145	78		22.0	0.108	28.0	22.5	0.131				3.0	
40	147	80		27.2	0.120	38.8	31.0	0.115				NMT	

Table B-3f: S-34 Orientation; Initial Pressure = 17.7 psia

Table B-3: Test Results of Orientation Study - Set II; 3 mil Foil, 38 inch Expansion, Density = 2.75 $\#/ft^3$ (Continued)

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (in.)	Remarks
0	67	61	32	3.54		3.5	0.141					4.5	0.145	8.0	
10	74	63	32	3.54	6.0	5.5	0.113				7.0	6.0	0.113	NMT	
20	72	62	32	3.54	9.4	8.8	0.134				9.5	8.4	0.130	<1	
30	76	64	32	3.54		12.5	0.154				13.5	12.6	0.151	NMT	
40	78	53	32	3.54		26.5	0.141				28.0	27.5	0.140	NMT	

Table B-4a: Initial Pressure = 14.7 psia

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (in.)	Remarks
0	66	58	32	3.54		6.5	0.125					8.5	0.122	1.0	
10	68	62	32	3.54		8.5	0.123				11.0	9.5	0.109	NMT	
20	71	61	32	3.54	17.0	15.5	0.100				21.0	19.5	0.103	NMT	
20	73	64	32	3.54	15.0	13.5	0.123				18.0	14.6	0.126	NMT	Tank was not Opened From Previous Test
30	77	52	32	3.54		25.0	0.118				27.5	24.8	0.113	9.0	
40	79	55	32	3.54		43.0	0.124				38.0	36.0	0.121	NMT	

Table B-4b: Initial Pressure = 17.7 psia

NOTE: The 38 inch expansion is reported in Table B-3c and B-3d - S-33 Orientation

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (in.)	Remarks
0	85	78	44	2.33		9.4	0.125				12.5	10.0	0.113	NMT	
10	86	80	44	2.33		12.8	0.139					11.9	0.135	NMT	
20	87	77	44	2.33		13.4	0.137					14.4	0.134	NMT	
30	88	78	44	2.33		16.6	0.121				25.6	20.0	0.115	NMT	
40	89	79	44	2.33		24.0	0.112				35.5	27.2	0.101	NMT	

Table B-4c: Initial Pressure = 14.7 psia

Table B-4: Test Results - 3 mil Foil

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (in.)	Remarks
0	80	76	44	2.33		11.6	0.102				14.4	12.8	0.091	NMT	
10	81	72	44	2.33		18.2	0.121				23.0	19.0	0.117	NMT	
20	82	74	44	2.33		26.8	0.100					30.0	0.097	NMT	
30	83	75	44	2.33		33.0	0.102					35.0	0.094	NMT	
40	84	77	44	2.33		41.8	0.100				48.8	42.8	0.090	NMT	

Table B-4d: Initial Pressure = 17.7 psia

Table B-4: Test Results - 3.0 mil Foil (Continued)

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (in.)	Remarks
0	41	46	32	2.33		5.0	0.150					5.0	0.150	NMT	~11% Excess Material Used

Table B-5a: Initial Pressure = 14.7 psia

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (in.)	Remarks
0	42	47	32	2.33		7.5	0.060				10.8	9.0	0.070	NMT	~11% Excess Material Used
10	46	61	32	2.33		13.0	0.105				17.5	14.5	0.098	4.5	
20	44	37	32	2.33		17.0	0.129					16.8	0.134	NMT	
20	45	56	32	2.33	25.0	23.0	0.100					23.0	0.103	12	
20	47	57	32	2.33		22.0	0.115					21.5	0.115	NMT	
30	48	55	32	2.33		31.0	0.113				39.0	32.0	0.089	NMT	

Table B-5b: Initial Pressure = 17.7 psia

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (in.)	Remarks
0	148	65	35	2.17		8.0	0.136		8.0	0.133				NMT	
10	152	75	35	2.17	9.2	8.0	0.114		8.5	0.114				NMT	
20	153	76	35	2.17	12.0	11.2	0.099	14.4	11.2	0.097				NMT	
30	156	73	35	2.17		25.5	0.111	26.0	25.2	0.113				NMT	

Table B-5c: Initial Pressure = 14.7 psia

Table B-5: Test Results - 2.0 mil Foil

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Foil Comp. (in.)	Remarks
0	49	57	35	2.17	7.3	7.0	0.103				8.5	7.3	0.101	NMT	
0	149	68	35	2.17		8.0	0.141	8.8	8.0	0.138				NMT	
0	150	81	35	2.17		9.6	0.124		9.2	0.121				NMT	
10	53	62	35	2.17		12.[illegible]	0.093				16.0	13.5	0.093	3.0	
10	151	83	35	2.17		13.5	0.116		13.5	0.114				NMT	
20	54	63	35	2.17		20.0	0.118				22.0	20.0	0.124	4.0	
20	55	62	35	2.17		17.5	0.115				18.0	17.4	0.113	4.0	
20	154	67	35	2.17		20.4	0.169	21.8	20.4	0.105				NMT	
30	56	53	35	2.17	28.2	27.5	0.108				37.0	28.0	0.088	NMT	
30	155	72	35	2.17		31.0	0.108	30.0	28.8	0.108				NMT	
40	57	56	35	2.17		37.0	0.113				52.0	42.8	0.090	---	Batts Moved too Much to Record

Table 3-5d: Initial Pressure = 17.7 psia

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Foil Comp. (in.)	Remarks
0	58	59	44	1.58		14.0	0.089					16.0	0.089	3.0	
0	59	52	44	1.58		12.5	0.113					13.0	0.085	3.0	
10	60	60	44	1.58		20.5	0.105					20.5	0.100	3.0	
10	65	63	44	1.58		19.0	0.11[illegible]					20.5	0.105	NMT	
20	61	59	44	1.58		27.5	0.103				30.0	28.0	0.095	4.0	
20	62	60	44	1.58		23.0	0.105				33.5	25.0	0.087	NMT	
30	63	60	44	1.58		34.0	0.101				43.0	38.0	0.090	---	Batts Moved too Much to Record
40	64	62	44	1.58		51.0	0.103					55.0	0.090	NMT	

Table B-5e: Initial Pressure = 17.7 psia

Table B-5: Test Results - 2.0 mil Foil (Continued.

Comb. Void (%)	Test No	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Remarks: Foil Comp. (in.)	Remarks
0	95	73	32	1.75		6.4	0.184					6.4	0.184	NMT	
10	96	75	32	1.75		7.6	0.140				12.0	8.8	0.140	NMT	
20	97	75	32	1.75		20.5	0.136					22.0	0.131		
30	98	76	32	1.75		29.0	0.125				42.0	30.0	0.120	16	
40	99	75	32	1.75		37.5	0.124				45.0	37.0	0.121	21	

Table B-6a: Initial Pressure = 14.7 psia

0	90	[illegible]	32	1.75	13.2	12.5	0.100				15.4	14.8	0.100	NMT	
10	91	74	32	1.75		18.5	0.129				19.6	18.0	0.126	NMT	
20	92	77	32	1.75		23.0	0.106				26.7	23.3	0.081	17	
30	93	74	32	1.75		37.0	0.106				46.5	38.4	0.088	23	
40	100	80	32	1.75		45.0	0.129				52.0	44.4	0.109	25	

Table B-6b: Initial Pressure = 17.7 psia

0	101	74	38	1.46		8.8	0.140					12.8	0.106	NMT	
10	102	76	38	1.46		12.5	0.141					12.5	0.130	NMT	
20	103	73	38	1.46		16.8	0.115					20.0	0.109	12	
30	109	78	38	1.46		24.8	0.108				31.0	27.2	0.100	12	First 2 Layers of Foil Melted

Table B-6c: Initial Pressure = 14.7 psia

Table B-6: Test Results - 1.5 mil Foil

Comb. Void (%)	Test No.	Ta (°F)	Exp. (in.)	Density (lbs/ft^3)	ΔP_1 (psid) Peak	ΔP_1 (psid) Average	Δt_1 (sec)	ΔP_2 (psid) Peak	ΔP_2 (psid) Average	Δt_2 (sec)	ΔP_3 (psid) Peak	ΔP_3 (psid) Average	Δt_3 (sec)	Foil Comp. (in.)	Remarks
0	107	76	38	1.46		9.8	0.144					9.0	0.140	NMT	
0	126	83	38	1.46		22.4	0.061		23.2	0.058				3.0	
10	106	73	38	1.46		23.0	0.078				32.4	25.2	0.071	6.0	
10	127	84	38	1.46		20.0	0.088		19.0	0.084				NMT	
20	108	80	38	1.46		22.0	0.094				24.5	22.8	0.090	9.0	First Layer of Foil Melted
20	128	85	38	1.46		28.0	0.077		26.0	0.073				NMT	
30	110	80	38	1.46		33.0	0.091							NMT	

Table B-6d: Initial Pressure = 17.7 psia

Table B-6: Test Results - 1.5 mil Foil (Continued)

SECTION IV

EFFECTS OF STRAND WIDTH

This testing was done by VIPL, Explosafe Division (Reference 20) in a flame tube similar to the AFWAL/PO flame tube. Although the testing to evaluate the effects of strand width (Figure A-2) was not done by the AFWAL/PO it is worthwhile to discuss these results. The testing was done with 3.0 mil thick material at two strand widths, type 850 has a strand width of 0.040 inch and the type 851 has a strand width of 0.055 inch. By changing the strand width the cell size is changed which also changes the densities and surface areas at a constant expansion for each strand width. But, the density of both types is proportional to the surface areas as shown in Table B-7 and Figure B-6 (References 20 and 21). Results indicate that the combustion overpressure is lower for the 0.040 inch width than for the standard 0.055 inch width at the same densiti and surface areas (see Figure B-7 and B-8). This effect is attributed mainly to the reduction of the cell size when the strand width is reduced. Further investigation of this phenomenon with the 2.0 mil material should be accomplished since this will provide an improvement in combustion suppression with weight reduction over the standard 0.055 strand width.

TABLE B-7

CHARACTERISTICS OF 3.0 MIL FOIL TYPES 850 and 851

Expansion (Inches)	Type 850 (0.040" x 0.003")		Type 851 (0.055" x 0.003")	
	Surface Area (ft^2/ft^3)	Density ($\#/ft^3$)	Surface Area (ft^2/ft^3)	Density ($\#/ft^3$)
32	170.5	3.54	176.5	3.61
33	167.5	3.40	170.5	3.49
34	163.5	3.34	164.5	3.38
35	160.5	3.28	158.7	3.27
36	157.0	3.23	153.0	3.18
37	153.8	3.18	147.0	3.05
38	150.2	3.11	141.0	2.94
39	147.0	3.05	135.0	2.83
40	143.5	2.99	129.0	2.72
41	140.2	2.93	123.0	2.60
42	137.0	2.87	117.0	2.50

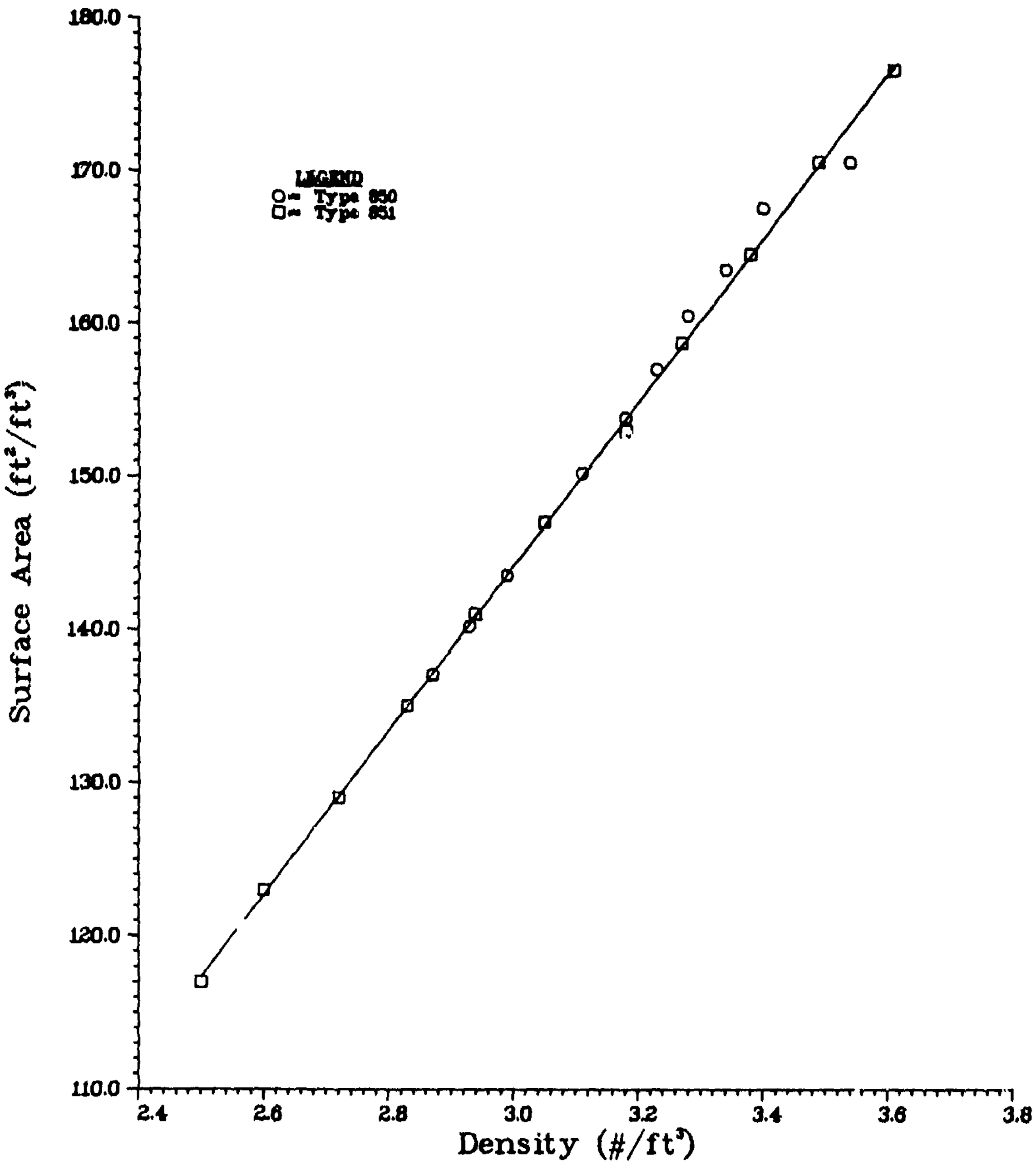


Figure B-6. Surface Area Versus Density - Type 850 and 851 Foils

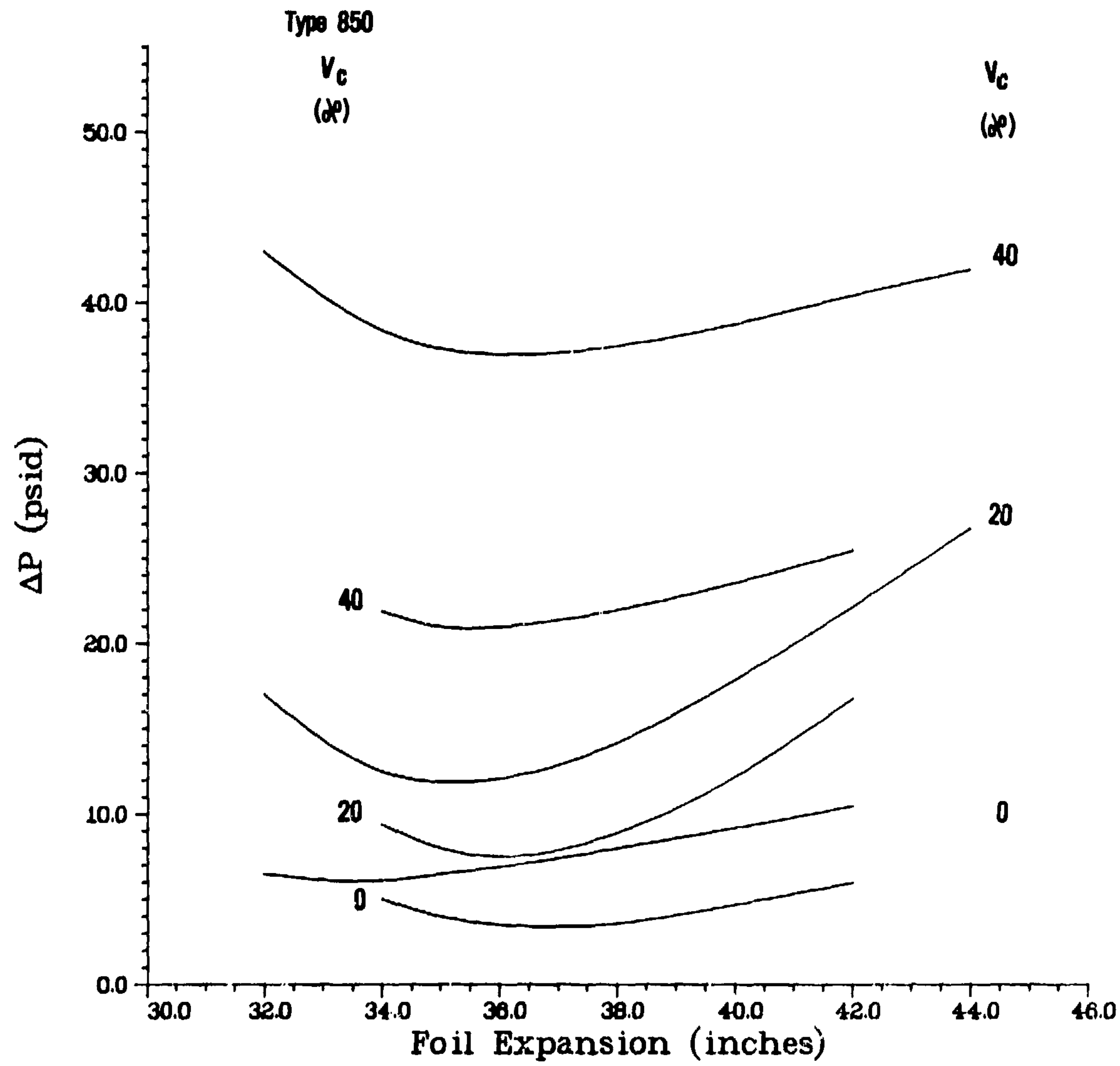


Figure B-7. ΔP Versus Foil Expansion - P_I = 3 psig

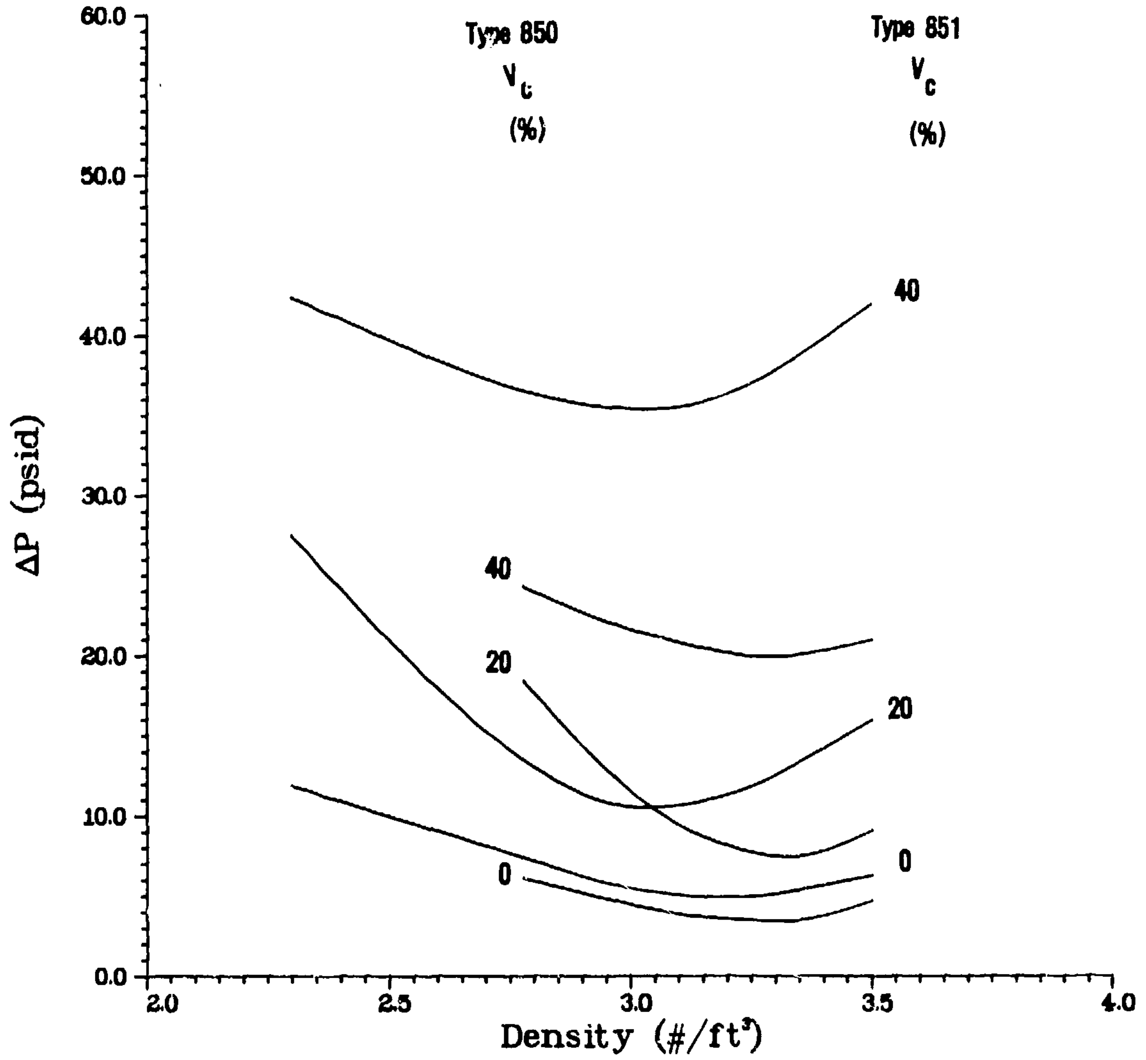


Figure B-8. ΔP Versus Density - P_I = 3 psig

SECTION V

COMPARISON OF EXPLOSAFE WITH THE COARSE PORE BLUE FOAM

The testing of the blue foam was performed under a previous in-house project (Reference 26). The foam tested was manufactured by Scott as a hybrid polyether polyurethane foam and identified by the color and pore size. The buns of blue foam were identified as W957L bun 7-5 which had a pressure drop between 0.201 and 0.205 inches of water and W957L bun 1-3 with a pressure drop between 0.155 and 0.162 inches of water. The density of both buns were 1.53#/ft^3. The standard density of the foam that is currently manufactured is 1.35#/ft^3. Table B-8 gives the results of the flame tube testing at an initial pressure of 3 psig. Figure B-9 shows the curves of combustion overpressure versus combustion void for the foam and the 2.0 mil Explosafe at 2.17#/ft^3.

Also, note that the time to peak combustion overpressure is greater for the foam than for the Explosafe. For an empty tank at a 5% by volume propane to air mixture the typical time to peak combustion overpressure is 0.40 seconds, for the foam with less than 20% voiding the time is typically between 0.24 and 0.39 seconds and for the Explosafe (2.0 mil, 2.17#/ft^3) with less than 20% voiding the time is typically between 0.09 and 0.12 seconds.

TABLE B-8
FLAME ARRESTOR RESULTS OF RETICULATED FOAM

Test Number	Pa (psia)	Ta (°F)	Combustion Void (%)	ΔP_3 (psid)	Δt_3 (sec)	Remarks
76-16	14.25	63	0	4.5	1.42	Bun (7-5)
76-17	14.25	62	5	5.0	1.18	Bun (7-5)
76-22	14.5	61	20	12.0	0.28	Bun (1-3) used Tests 22 thru 34
76-23	14.46	63	20	14.0	0.24	
76-24	14.45	66	10	8.0	0.39	
76-25	14.45	68	20/ 13	24.0	0.19	Double Void; 20% Near Spark, 13% on Opposite End
76-26	14.45	68	31	18.0	0.23	
76-27	14.41	64		34.5	0.17	
76-28	14.38	66	48	37.0	0.15	
76-29	14.38	68	60	65.0	0.11	
76-30	14.38	70	69	75.0	0.11	
76-31	14.32	65	20	11.0	0.25	
76-32	14.32	70	20/ 20	17.5	0.22	Double Void; 20% Near Spark, 20% on Opposite End
76-33	14.17	69	50	40.0	0.13	
76-34	14.21	69	80	84.0	0.15	

NOTE: Foam Type: Scott Hybrid Polyether Coarse Foam, Blue W957L (7-5), (1-3)
Initial Pressure: 3 psig; 5% Propane in Air
Density = 1.53 #/ft^3

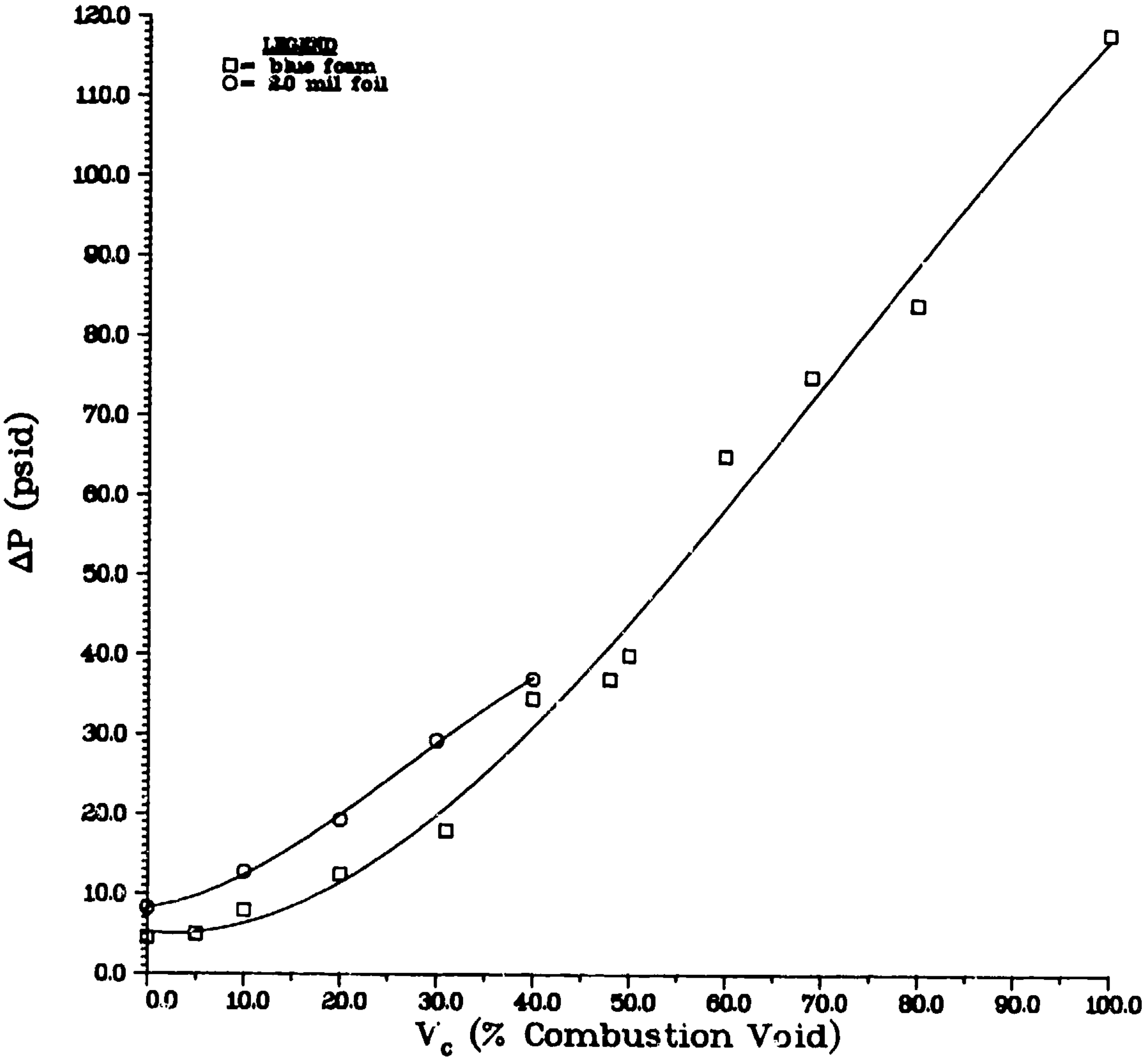


Figure B-9. Blue Foam and 2.0 mil Foil (2.1 #/ft^3) Comparison - P_I = 3 psig

APPENDIX C

TEST RESULTS OF ARMY TESTING

SECTION I

HEI-T AND API IGNITION OF PROPANE/AIR MIXTURES

The baseline combustion tests consisted of 23mm HEI-T detonations and caliber .30 incendiary impacts into varying concentrations of propane and air. All testing was done at atmospheric pressure.

The 23mm HEI-T tests were conducted from 2 to 5 percent to determine what ratio would result in peak overpressure. The stoichiometric concentration of propane in air is 4.02% by volume. These tests were conducted at two tank volumes and the data is given in Table C-1. It can be observed in Table C-1 and Figure C-1 that the maximum peak combustion overpressure and maximum impulse occur at 4.0 volume percent propane. Perhaps the most significant observation made during these tests is that as the mixture approached the stoichiometric concentration the delay between projectile detonation and gas combustion disappeared resulting in higher peak combustion overpressures. The transducer data taken at the 3.0 and the 4.0 volume percent mixtures are compared in Figure C-1b and the pressure traces for each are shown in Figure C-2 which illustrates this phenomenon.

The results of the tests to determine the "worse case" propane/air mixture response to API ignition source are summarized in Table C-2 and Figure C-3. The peak combustion pressure was not as sensitive to the propane/air ratio as it was for the HEI-T tests. A concentration of 4.5 volume percent was chosen for use in the tank filler tests using API ammunition.

Shot No.	C_3H_8 (%)	Combustion Overpressure (psig)				
		Transducer Location Number				AVG
		1	2	3	6	
98	3.0	86(76.1)	92(86.9)	89(85.2)	99(90.3)	91.5(84.6)
99	3.5	91(86.9)	110(103.2)	111(88.1)	111(102.8)	102.8(95.3)
100	4.0	163(92.4)	212(108.7)	148(102.3)	178(116.7)	175.3(108.0)
101	4.5	152(92.4)	152(108.7)	125(102.3)	156(111.1)	146.3(103.6)

NOTE: First number is maximum pressure; number in parenthesis is pressure about 30 M-Sec after impact. All units psig.

Table C-1a: Peak Combustion Pressure (psig) for Various Propane/Air Mixtures Initiated by 23mm HEI-T - Tank Volume = 40.24 Cubic Feet

Shot No.	Impulse (lb-sec/psi)				
	Transducer Location Number				AVG
	1	2	3	6	
98	25.4	30.2	25.9	28.1	27.4
99	22.5	31.5	24.3	28.1	26.6
100	28.4	38.6	30.8	26.9	31.2
101	29.5	29.5	23.0	25.2	26.8

Table C-1b: Impulse $(\frac{\text{lb-sec}}{\text{psig}})$ Between Impact and 400 M-Sec

Shot No.	C_3H_8 (%)	Combustion Overpressure (psig)			
		Transducer Location #			AVG
		1	2*	3	
68	3	62.5		59.4	61.0
69	4	83.3		67.9	73.6
70	5	66.7		69.1	67.9

Table C-1c: Additional Testing to Verify Optimum Propane/Air Mixture for HEI Ignition in the Smallest Tank Configuration (15.55 Cubic Feet). Combustion Pressures (psig) are Shown About 40 M-Sec After Impact

*Transducer #2 Damaged During Testing

Table C-1: Baseline Combustion Tests - 23mm HEI-T

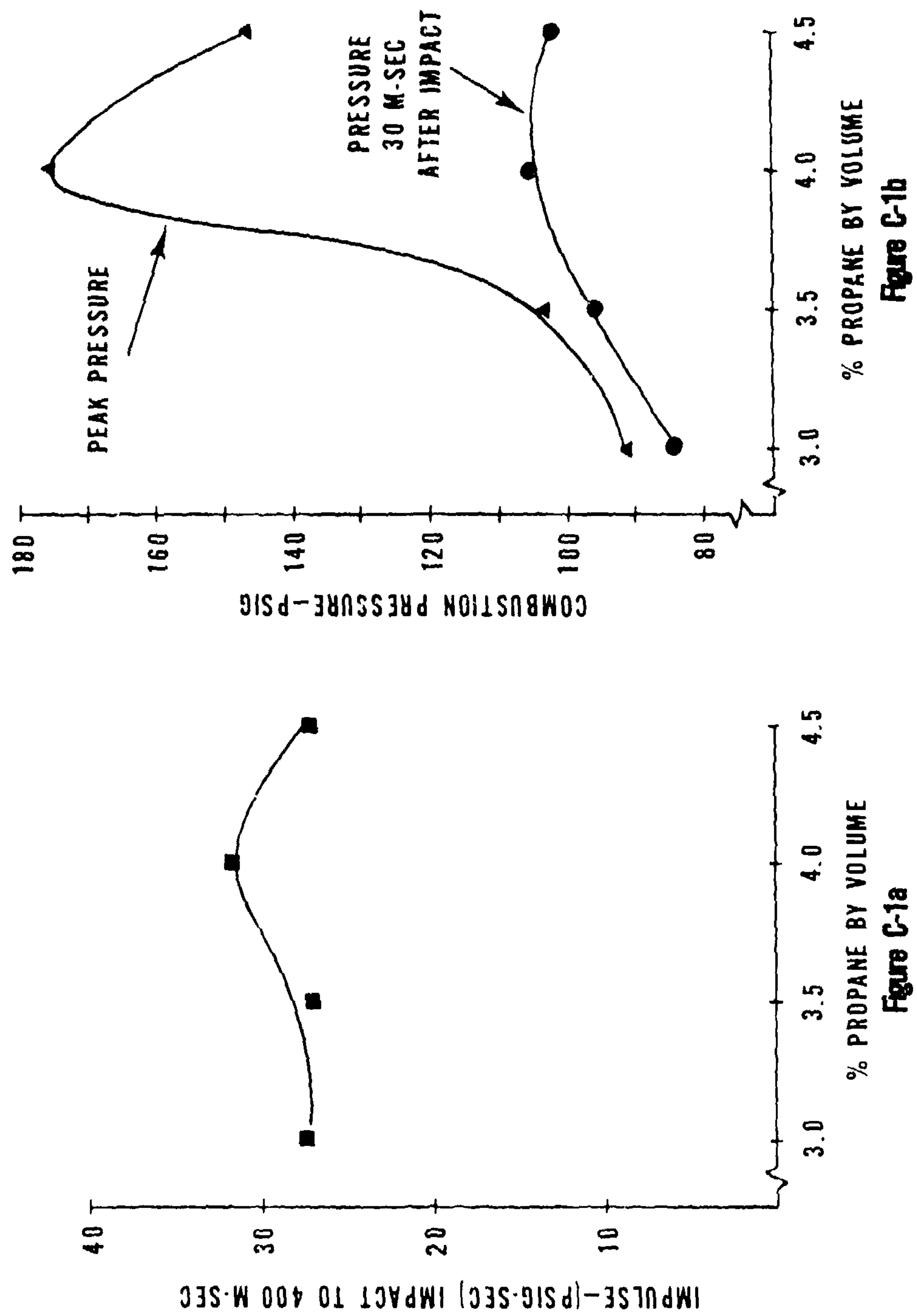


Figure C-1. Ignition of Various Propane Air Mixtures by 23mm HEI-T
Tank Volume = 40.24 Cubic Feet

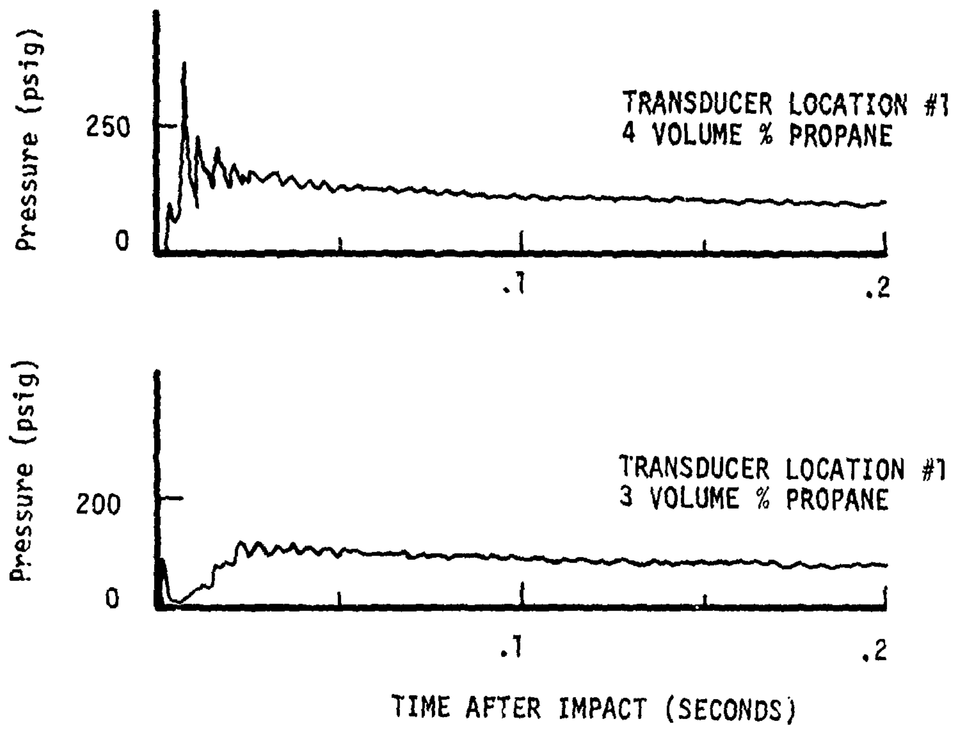


Figure C-2. Pressure Traces - Comparison Between Combustion Responses Obtained at 3.0 and 4.0 Volume Percent Propane/Air Mixtures Ignited by 23mm HEI-T Impact

TABLE C-2

BASELINE COMBUSTION TESTS - CALIBER .30 API

Shot #	$\%C_3H_8$	Peak Combustion Overpressure (psig)					
		Transducer Location Number					AVG
		1	2	3	5	6	
119	3.5	97.1	137.7	121.3	106.5	104.8	113.5
120	4.0	85.5	120.3	108.2	101.6	93.5	101.8
121	3.8	76.8	107.2	100.0	90.3	82.3	91.3
122	4.3	88.4	115.9	109.8	103.2	96.8	102.8
123	3.5	82.6	89.9	82.0	77.4	64.5	81.5
124	4.0	92.8	110.1	103.3	93.5	75.8	95.1
125	4.5	110.1	123.2	116.4	109.7	90.3	110.0
126	5.0	108.7	129.0	114.8	106.5	90.3	109.9
127	5.5	111.6	113.0	116.4	106.5	93.5	108.2

TABLE C-2a: TESTS TO ESTABLISH OPTIMUM PROPANE/AIR MIXTURE TO BE USED WITH API IGNITION SOURCE. TESTS CONDUCTED IN LARGEST TANK CONFIGURATION (40.24 CUBIC FEET)

Shot #	$\%C_3H_8$	Peak Combustion Overpressure (psig)				
		Transducer Location Number				AVG
		1	2	3	5	
134	3.5	110.9	122.0	136.0	131.2	125.0
135	4.0	21.9	70.6	59.0	72.0	55.9
136	4.5	40.9	89.7	75.4	83.2	72.3
137	5.0	99.3	136.7	129.5	131.2	124.2
138	4.5	92.0	139.7	127.9	126.4	121.5
139	4.0	90.5	127.9	123.0	121.6	115.8

TABLE C-2b: TESTS TO ESTABLISH OPTIMUM PROPANE/AIR MIXTURE TO BE USED WITH API IGNITION SOURCE. TESTS CONDUCTED IN SMALLEST TANK CONFIGURATION (15.55 CUBIC FEET)

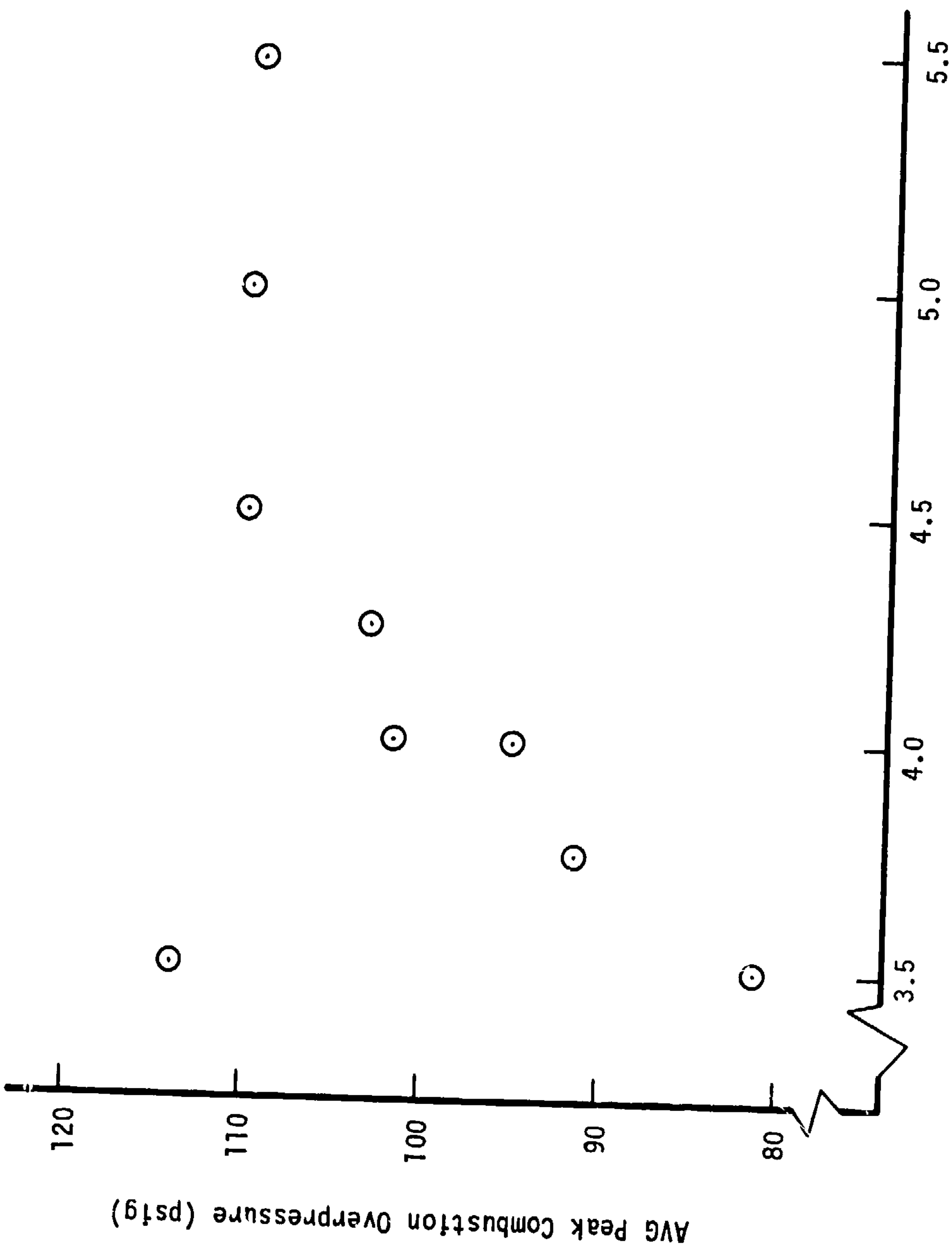


Figure C-3. Results of Tests to Establish Optimum Propane/Air Mixtures to be used with API Ignition Source - Tank Volume = 40.24 Cubic Feet

SECTION II

BALLISTIC TEST DATA ON EXPLOSAFE AND BLUE FOAM

Table C-3, C-4 and C-5 show the results of the 23mm HEI-T testing. Peak combustion overpressures are given under the transducer location number and the average of these peaks is given under AVG. Table C-6 gives the results of the .30 caliber API tests.

TABLE C-3

EXPLOSAFE AND BLUE FOAM 23mm HEI-T TEST DATA - TANK VOLUME OF 40.24 CUBIC FEET

Test No.	Filler Type	Installation Configuration	Peak Combustion Overpressure (psig)				
			Transducer Location Number				AVG
			1	2	3	6	
102	Explosafe 3.0 mil	Full	5.0	0	0	0	3.0
103	Explosafe 3.0 mil	40% Void @ Front	27.2	28.5	26.0	27.8	27.4
104	Explosafe 3.0 mil	40% Void @ Rear	13.6	14.9	12.8	13.9	13.8
105	Explosafe 2.0 mil	Full	6.4	7.3	5.7	2.8	5.6
106	Explosafe 2.0 mil	40% Void @ Front	20.6	23.1	24.1	25.0	23.2
107	Explosafe 2.0 mil	40% Void @ Rear	27.1	27.9	31.3	34.7	30.3
108	Explosafe 1.5 mil	Full	5.0	7.3	5.0	9.7	5.5
109	Explosafe 1.5 mil	40% Void @ Front	15.5	25.5	25.7	26.4	23.3
110	Explosafe 1.5 mil	40% Void @ Rear	20.6	19.4	25.6	23.6	22.3
116	RPF	Full	5.0	6	5.0	0	3.0
117	RPF	40% Void @ Rear	6.8	14.3	10.4	12.9	11.1

TABLE C-4

EXPLOSAFE AND BLUE FOAM 23mm HEI-T TEST DATA - TANK VOLUME OF 15.5 CUBIC FEET

Test	Filler Type	Installation	Peak Combustion Overpressure (psig)			
			Transducer Location Number			AVG
			1	2	3	
69	None		93.8		75.2	87.6
71	RPF	Full	12.0	4.0	8.0	8.0
72	RPF	40% Void @ Front	48.0	34.0	28.3	36.8
73	RPF	40% Void @ Rear	44.6	25.0	32.7	34.1
74	Explosafe 3.0 mil	Full	10.8	3.3	6.2	6.8
75	Explosafe 3.0 mil	40% Void @ Front	50.5	36.2	34.9	40.5
76	Explosafe 3.0 mil	40% Void @ Rear	15.5	9.5	11.7	12.2
77	Explosafe 1.5 mil	Full	17.5	7.6	11.7	12.3
78	Explosafe 1.5 mil	40% Void @ Front	48.5	38.1	38.8	41.8
79	Explosafe 1.5 mil	40% Void @ Rear	34.0	25.7	24.3	28.0
80	RPF	Full	9.7	5.7	7.8	7.7
81	Explosafe 3.0 mil	Full	9.7	3.8	4.9	6.1
82	Explosafe 1.5 mil	Full	18.4	9.5	15.5	14.5
83	Explosafe 2.0 mil	Full	7.5	5.9	9.3	7.6
84	Explosafe 2.0 mil	40% Void @ Front	62.3	37.6	41.2	47.0
85	Explosafe 2.0 mil	40% Void @ Rear	11.3	12.8	16.5	15.5

TABLE C-5

EXPLOSAFE 23mm HEI-T TEST DATA - TANK VOLUME 29.93 CUBIC FEET

Test No.	Percent Void	Transducer Location Number					AVG
		1	2	3	5	6	
149	7.6	18.3	8.6	10.1	9.6	11.8	11.7
150	12	6.5	7.0	9.0	4.5	8 6	7.1
151	15	6.5	4.3	10.1	9.0	9.7	7.9
152	22	21.5	11.8	12.4	13.5	11.8	14.2
153	27	19.4	6.5	11.2	9.0	11.3	11.5

TABLE C-5a: PEAK COMBUSTION PRESSURE, PSIG, RECORDED DURING VOIDING TESTS OF .002" EXPLOSAFE IN "F" TANK AND AFT EXTENSION

Test No.	Front*	Rear**	Shaped	Front (3 3/4)
149	5	4	1	1
150	6	3	1	1
151	5	3	1	1
152	3	4	1	1
153	4	3	1	1

TABLE C-5b: .002" EXPLOSAFE BATTS USED IN VOIDING TESTS

*6 Buns Required for Fill-Each Bun 7.6% Total Volume
**4 Buns Required for Fill-Each Bun 12% Total Volume

TABLE C-6
EXPLOSAFE API TEST DATA

Test No.	Filler Type	Installation Configuration	Transducer Location Number					AVG
			1	2	3	5	6	
128	Explosafe 1.5 mil	Full	∿0	∿0	∿0	∿0	∿0	∿0
129	Explosafe 1.5 mil	40% Void @ Front	10.9	10.9	12.7	8.9	8.1	10.3
130	Explosafe 1.5 mil	40% Void @ Rear	15.9	12.0	10.7	12.9	11.3	12.6
131	Explosafe 2.0 mil	Full	∿0	∿0	∿0	∿0	∿0	∿0
132	Explosafe 2.0 mil	40% Void @ Front	14.7	11.2	8.2	9.6	8.1	10.4
133	Explosafe 2.0 mil	40% Void @ Rear	16.2	8.0	9.8	10.4	10.9	11.0

TABLE C-6a: PEAK COMBUSTION OVERPRESSURES (PSIG) MEASURED IN THE LARGEST TANK CONFIGURATION (40.24 CUBIC FEET) CONTAINING VARIOUS VOID FILLERS DURING API IGNITION OF PROPANE/AIR MIXTURES

Test No.	Filler Type	Installation Configuration	Transducer Location Number				AVG
			1	2	3	5	
140	Explosafe 1.5 mil	Full	∿0	∿0	∿0	∿0	∿0
141	Explosafe 1.5 mil	40% Void @ Front	21.2	26.5	29.5	24.0	25.3
142	Explosafe 1.5 mil	40% Void @ Rear	5.8	4.4	5.6	7.2	6.0
143	Explosafe 2.0 mil	Full	∿0	∿0	∿0	∿0	∿0
144	Explosafe	40% Void @ Front	32.8	35.3	44.3	36.8	37.2
145	Explosafe 2.0 mil	40% Void @ Rear	8.0	8.1	7.4	10.4	8.5

TABLE C-6b: PEAK COMBUSTION OVERPRESSURES (PSIG) MEASURED IN THE SMALLEST TANK CONFIGURATION (15.55 CUBIC FEET) CONTAINING EXPLOSAFE DURING THE API IGNITION OF PROPANE/AIR MIXTURES

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